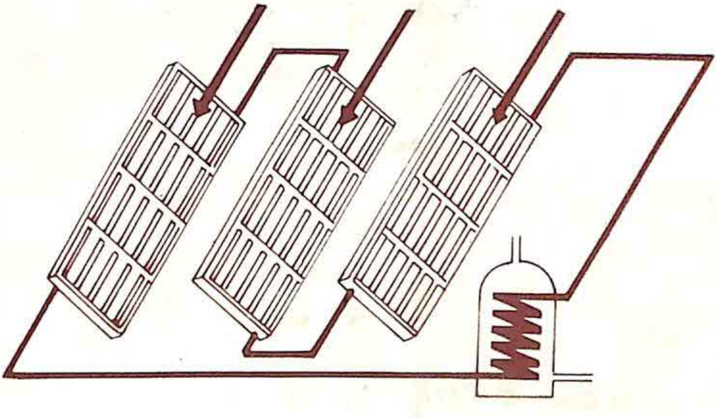
NON-CONVENTIONAL SOURCES OF ENERGY



H.C. Jain

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The supply of fossil fuels, from which man has so far obtained energy, is limited. With the prospect of drying up of conventional energy sources staring them in the face, scientists have turned their attention to alternate energy sources. This book, written in popular style, will be of interest to students who want to know about the non-conventional sources of energy, their potential and the problems encountered in their viability.

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NON-CONVENTIONAL
SOURCES OF ENERGY

Non-Conventional Sources of Energy

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FOREWORD

The availability of energy resources is the concern of world over today. As the supply of fossil fuels is limited, attempts are being made to harness alternate energy sources. There is emphasis particularly on developing low cost technology for using renewable sources of energy. It is with these reasons that the topic 'alternate energy sources' comes under the category of thrust area of various scientific and research organizations and also forms an important part of curriculum at various standards in our country and other parts of the world.

The present book written by Dr. H.C. Jain initially deals with energy perspectives, traces the history of the ways of using energy in the past and then takes a stock of the resources available and makes a mention of how long will they last at the present rate of consumption.

I hope this profusely illustrated book will be used as a popular reading book by the science students thereby creating interest in knowing about alternate energy sources, its potential and existing problems.

Prof. P.L. Malhotra
Director,
N.C.E.R.T., New Delhi.

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1

Energy Perspectives

We all use up energy all the time. Right from the time we get up and until we go to bed or even while we are asleep, we require energy for breathing, to keep our hearts beating doing the work and maintaining the temperature of our bodies. Besides, we move in cars, buses, trains and aeroplanes, study under the lighting bulbs, keep our houses cooled with fans, coolers and airconditioners and warmed with heaters. Also, we run our industries with electricity which supply us manures, tractors and other materials to be used to grow the plants to give us food, cloth for covering us, cement for building houses for shelter, books and newspapers for increasing our knowledge, T.V. and radio for entertainment and other countless things necessary for us, the society and this civilization to prosper. Thus, we have made use of energy in the past, are still making use of it and more of it will be used in future. Estimates indicate that every 15 years, the demand will be nearly doubled at the present rate of consumption. Wherefrom will all this energy come?

Energy has its own story and calendar. In the past, for thousands of years man depended for energy on his own muscles, slaves and the tamed animals. Time rolled on and the common source of energy became animal dung and wood. Indiscriminate use of wood coupled with the growing population led to deforestation. Man needed other energy sources. During the period 4000 to 1000 B.C. as we switched over from bronze to iron age, other energy sources, *viz.* water and wind were harnessed by man. Egyptian rock carvings indicate the use of wind energy by the sailing ships around 3300 B.C. Also, the water-wheels were used for irrigating the fields by the Babylonians 3000 years ago. In the following period wind and water power have been used in windmills and watermills and for generating electricity as well. At some stage, (probably in about 1000 B.C. by the Chinese), man also learnt the use of energy obtained from coal by burning it. As the time passed by, new energy sources, oil and natural gas, found their use. In ancient times, man knew the oil in the areas which were on the earth's surface. It was burnt in oil-fired torches in about 82 A.D. in the temple of Jupiter in Rome. By 400 A.D. the natural gas was used for evaporating the brine (salt water) by burning the gas in the brine wells. The use of these sources continued for many centuries. But as the demand for energy increased, the twentieth century has also seen the dreaded source of energy—the nuclear energy.

The analysis thus will indicate that the main natural sources of energy are wood, water, wind, coal, oil, natural gas and the nuclear energy. They are known as primary energy sources as energy can be derived directly from such sources. In the following diagram you are given these sources on the left and the various works they can do on the right. Connect each of them by lines with the works it can do. Then join the sources and/or the works they can do with the electricity given in the middle.

Wood
Oil
Natural Gas
Falling Water
Coal
Nuclear reaction
Wind

Electricity

Cooking
Fire
Running railways
Running modern day locomotives
Heating the houses and offices
Running cars, trucks, buses and planes
Lighting houses
Preparing fertilizers
Cooling the houses and offices
Running the industries

It will be evident by now that the primary sources can be used in a variety of ways. The energy generated by man using suitable plants to convert the primary energy is termed as secondary such as steam power, hot water power, electrical energy and others. You will have noticed in the above diagram that the most convenient and versatile form of energy, however, is the electricity. It is for this reason that the demand for this energy has been growing at a rate faster than another form of energy.

Are all the sources indicated above sufficient enough to give us energy for all the times to come? This quest for energy shows that there are two types of sources. One—renewable, *i.e.* the sources which are stored by nature, *e.g.* water, wind, wood, etc. The other expendable, *i.e.* the sources which are vanishing too fast and not being restored under the present geological conditions, *e.g.* the fossil fuels, *i.e.* coal and petroleum (oil and natural gas).

How long will the expendable sources last? Obviously, it will depend upon their abundance and the energy consumption. Let us first have a look at the records of the past and the expected world energy consumption in near future.

World Energy Consumption

'000 billion KWH

Country	*1975*	*1980*	*1985*	*1990*
U.S.A.	72.0	86.3	102.9	121.2
W. Europe	49.1	62.6	75.2	87.2
Japan	13.4	20.4	26.7	34.0
Sino-USSR Block	63.7	82.0	94.0	109.0
Others	35.7	45.0	52.1	62.4
Total	233.9	296.3	350.9	413.8

The data indicates a rapid increase in the usage of energy with time. Within a period of 15 years, *i e.* from 1975 to 1990, the demand will become nearly 1.8 times.

Estimates of the world energy reserves of known energy resources suggest as follows:

Coal : 6,641 billion tonnes which will last upto 2500 A.D. at the present rate of consumption.

Petroleum Crude : 76 billion tonnes which will last upto 2100 A.D. at the present rate of consumption.

Natural Gas : 49,990 billion cubic metres which would last upto 2015 A.D. at the present rate of consumption.

Uranium : 761,400 tonnes which would last upto 2000 A.D. but resources would be unlimited if fast breeder reactor technology is perfected.

Estimates for reserves in the case of our country stand as follows:

Coal : 111,628 million tonnes.

Crude Oil: 370 million tonnes.

Natural Gas : 350 million cubic metres.

Uranium : No definite data is available.

Compared to world energy resources, how long will our sources last? Our coal and crude oil consumption in 1984-85 was approximately 15 and 3.5 crore tonnes respectively. With these data, it is easy to conclude that the situation in our country is also not good. Besides, we are a developing nation. Our per capita consumption of power is increasing at a rapid rate as is evident from the following table:

Year	Per Capita Consumption (KWH)
1950	18
1960-61	38
1970-71	90
1973-74	98
1979-80	131
1980-81	135
1984-85	212
Projections 1989-90	320

It will be seen from the above table that our per capita consumption in 1990 will be about 18 times as compared to that in 1950 which was a meagre 18 KWH. Besides, coal based thermal and diesel power houses contribute more than 60 per cent electricity generation in our country. It means that our technology for producing electricity is mainly dependent upon expending sources.

What will be our fate when the sources like fossil fuels are depleting so fast? The world has started realizing the inevitability of energy crisis if alternate sources are not suitably harnessed. It is with this idea that we are now looking for energy from renewable sources like wind, water, sun and the wastes. Of course, these sources have been in use in one form or the other in the past. But in the absence of cheap technology and their reliable use, no major breakthrough took place and these were never treated as conventional sources. Even the nuclear energy contributes not more than 3 per cent in electric power generation in our country. Thus, all these sources together with a few other emerging sources of energy are termed as non-conventional. A good deal of work is going on in this direction. The following pages describe the ways these sources may be used and the potential they possess.

2

Wind Energy

Wind energy is the energy from the air in motion with no cost to us. It is an inexhaustible source unlike fossil fuels as it will always remain with us. Its use had been recognized long long ago. According to Greek mythology, even before Christ, Phoenicians, Greeks, Egyptians and the people of ancient Rome made use of the direction of the wind to propel their ships. Columbus reached the shore of America due to the constant winds blowing from north-east to south west in the Northern hemisphere. Use of wind has also been made in the windmills. You can also make a windmill and see how does it work?

Take a very thin card or a stiff paper. Cut a square out of it. Fold along the diagonals and flatten out again. Cut along the diagonals up to 1 cm. of the centre as in figure 2. Fold the points A, B, C and D to the centre in turn in such a way that they lie

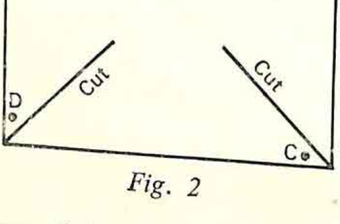

Fig. 2

on the top of each other. Push a strong pin through the centre and then into a stick. Be sure that the system is free to turn. Your windmill is now ready. Hold it vertically with the stick (on your side) and run or fix it in the handle of your bicycle while going to the school. What happens? Why do the blades rotate? Hold it horizontally under a ceiling fan or vertically before a table fan with the stick facing the fan in each case. Again you will see the blades rotating. Why? The oncoming stream of air from the fan is deflected by the blades of your windmill. This is the basic principle behind making use of wind energy. Similarly, in the windmills so far in use (see figure 3) the oncoming stream of air is deflected by the blades of the wind motor diagonally fitted on an axle. Each blade is acted upon by the reaction of a stream of air that rotates the wheel of the wind motor.

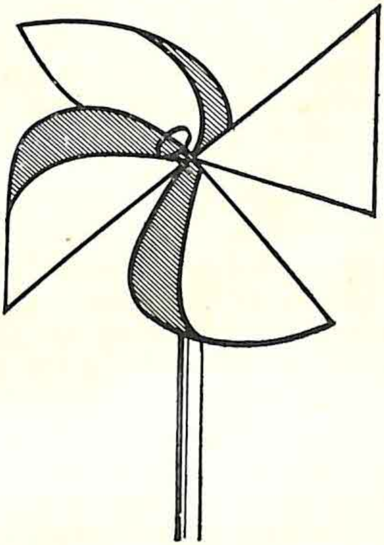

Fig. 3

Principle of Windmill

Now hold the windmill horizontally with the stick uppermost over a small source of heat. It should not be near enough to scorch. What happens? Remove the heat source under the windmill and watch what happens? Why do the blades stop rotating? The air in the vicinity of the burner, when heated, rises up. Cooler air takes its place. The air currents thus set up make the blades move. The existence of air currents may therefore be exploited to give kinetic motion to the windmills. Nature also provides us with such air currents. Do you know how?

According to Galileo, the air heated in the equatorial zone at a higher rate moves up. Cooler air from the northern and southern hemispheres move towards the equator giving rise to constant currents of air. It has been shown later that though this effect exists but it is of secondary importance. Helmholtz's findings indicate that the earth's rotation is mainly responsible for the general circulation of the atmosphere. When the earth rotates, it gives rise to a centrifugal inertial force. Thus the equatorial air masses are thrown to the upper atmosphere. In turn, the empty space is taken by the new layers of air coming in from the northern and southern hemispheres. Our knowledge regarding the atmospheric circulation is not yet complete. It requires further investigations.

Air currents are also set up due to periodic air flows from sea to land and backwards due to the difference in heat capacities of water in the seas and surface of the land.

Wind energy can be a permanent source of energy, as there are always air currents. It is estimated that about 175 to 219 thousand trillion watt hours/year wind energy can be produced from the world's winds. This is a very promising figure as it is about 2.7 times the total energy used on the planet. However, it has been found that by and large the wind velocities are low and the winds are not steady enough to give a uniform energy production. Also, there is a need to adjust the wind-powered generators so as to stabilize the energy parameters.

In India, research and development work on suitable windmill designs for lifting water and generating electricity along coasts and on the hills is in progress. There are classical windmills mainly in our country, U.K., Denmark and Holland and other places. These have been used mainly for water pumping and in some cases for power generation. In our country, under a demonstration plan, 575 windmills have been installed for water pumping purposes. Experiments are under way to devise suitable windmills. It is thought that the windmills of the future will be very much different from the present heavy structure with wooden cogs and wheels inside its base and those traditional large four-bladed sails. The blades or propellers may be made of titanium and carbon fibre materials as great strength will be required to meet those unexpected gusts of gale force winds. The propelling part will be mounted on a tall, narrow tower with gears at the top and part of the way down to get maximum amount of turning force into the generator on the ground. The shape of the propellers may be like that of a pre-jet age aircraft or blades at each end of a central beam mounted on the top of the tower. Thus these systems will be quite closer to the aircraft industry. That is why they are now being given the name 'aerogenerators'. See figure 4 (a) and (b) for different types of aerogenerators in the world.

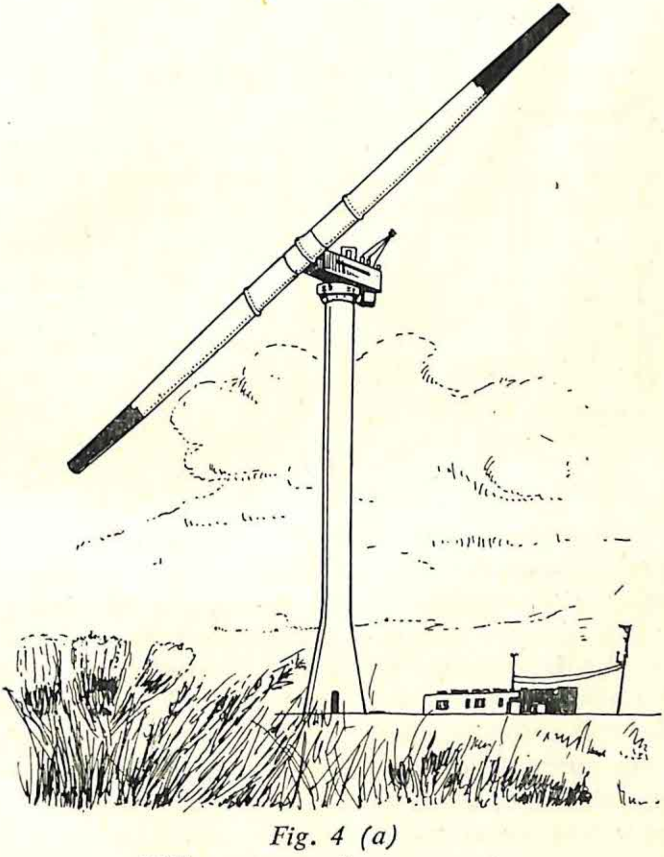

Fig. 4 (a)
Different types of aerogenerators

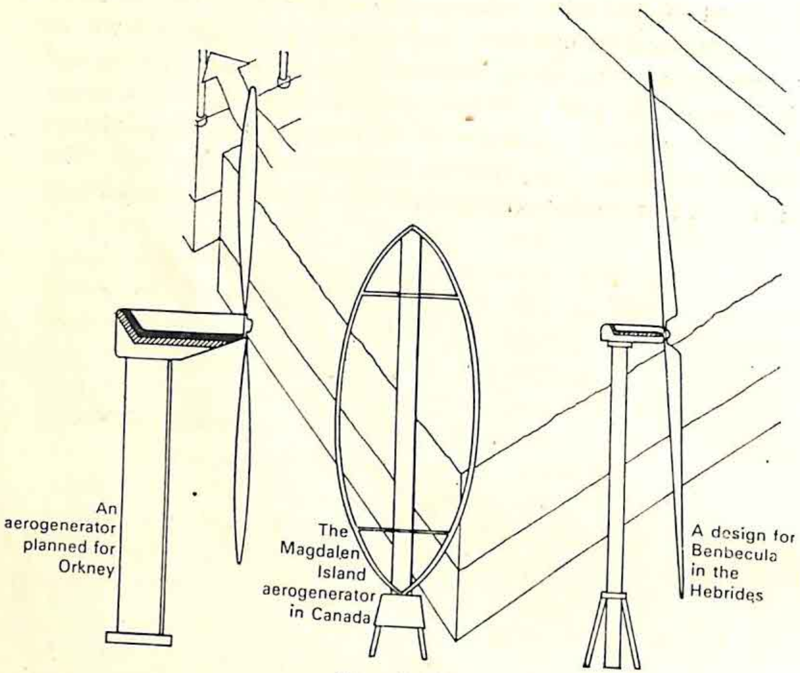
An aerogenerator planned for Orkney
The Magdalen Island aerogenerator in Canada
A design for Benbecula in the Hebrides

Fig. 4 (b)
Different types of aerogenerators in the world

13 small aerogenerators of 1 to 3 Kw capacity are to be used in remote areas for trial and demonstration purposes in our country. Also, an imported wind generator has been installed for the first time to operate a light house at Kanai-Creek in Gujarat. Electric generator which gives power output of 300 watts has been installed on an 18 metre high tower. The generator will charge a storage battery which in turn will operate an electrically operated revolving light house. So the future is probably going to see a number of 'wind farms' on acres of land installed with aerogenerators.

3

Energy from Oceans

Have you ever gone to the sea shore? How beautiful the scene is! Cold breeze embracing you, the waves coming endlessly, floating barrel or piece of driftwood bobbing up and down, sun shining over the surface of water heating it and the tides all the more adding to the unique feature of the oceans. Why are the waves, tides and the wooden block in motion ceaselessly? Yes, they possess energy? Could we translate their movements to fetch this energy and generate electricity? Also could we run turbines by making use of the ocean water heated from the sun. As these are everlasting phenomena, scientists have turned their attention to harness this perennial source of energy.

Looking in totality, the energy production methods could involve ocean waves, tides and tidal currents, ocean winds, ocean currents, salinity gradients, thermal energy conversion, ocean geothermals and the use of weeds on ocean water surfaces.

Tidal Energy

Out of all the above methods, the most popular and brought into practice so far is that of producing energy from tides. Tides —the rising and falling of the ocean—are produced by the astronomical gravitational forces of the sun and the moon. The effect of the moon is about 2.6 times that of the sun as the moon is nearer to earth. The effect, obviously is maximum when the earth, the moon and the sun are in one line.

How do the gravitational forces affect water in oceans? Newton provided an explanation like this. Suppose the earth is acted upon by the attraction of the moon in the direction LB.

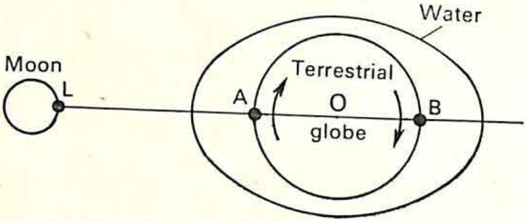

Fig. 5

It means that the acceleration of the earth due to this force is directed along LB only. While water at point A will have more acceleration than that of earth, the water at point B will have less acceleration than that of earth. This difference in acceleration causes water to shift as shown in figure 5. In the course of earth's rotation, the water bulges will move over its surface. This creates a phenomenon known as tidal friction. Tidal friction naturally tries to slow down the rotational velocity of the earth.

To get energy from the tides, we require the storage mechanism as is needed for hydropower generation. Besides, as we

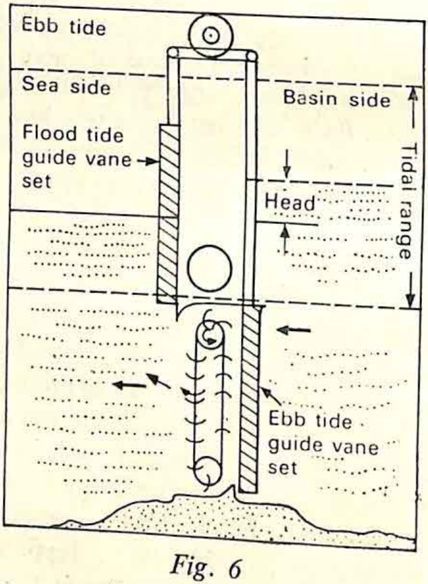

Fig. 6
Energy from tides

want to harness tidal power at the rising tide (flood tide) as well as at the receding tide (ebb tide), the lift translators are provided with two sets of vanes. Depending upon the direction of flow (ebb tide or flood tide) one or the other set of vanes is lowered so as to guide the water flow to a rotary device turning a generator (see figure 6).

Tidal energy has been known to man from time immemorial. In the past, various devices particularly mills were made to work by tidal power. Use of energy from tidal waves was made to irrigate fields in Germany and to saw firewood in Canada. In the last century a tidal power water engine served to supply water in London. At present, the tidal power plants in operation are on the La Rance estuary in France producing 230 MW of power, at Taliang in China having a capacity of 144 KW and experimental power plant in operation at Kislaya Guba in the Barents sea in USSR.

The main requirement for harnessing tidal energy is that the difference in low tide and high tide be large. In India, investigations by National Institute of Oceanography have been carried out on the use of tidal power. Gulfs of Kutch and Cambay on the West Coast and Sunderbans area on the east coast have been identified as the areas where tidal range is fairly high and tidal power could be developed.

The main disadvantage of tidal power plants is the unevenness in their working. There are variations in the tidal energy available through the lunar day and lunar month different from their solar counterparts. However, this disadvantage can be overcome if the tidal power plants are in joint operation with pumped storage plants. If during a period, more tidal energy is being produced than needed, the pumped storage plant uses the excess of energy in pumping water to the upper reservoir. On the other hand, if energy from tidal power plant decreases at any moment, the pumped storage plant generates electric power and delivers to the system. Such an assembly is quite attractive but costly.

It is estimated that the total global tidal power is only 2 per cent of the World's potential hydroelectric capacity. Besides, it involves high initial cost and the output will be variable in nature, if not supported by energy from pump storage plant.

Still the tidal power is quite important for its stability in areas of steep tides in comparison with hydropower which is very dependent on the seasons. Also, it is a renewable source of energy.

Energy from Waves

Unlike the tides which exhibit a regular but long periodic motion, waves keep the ocean water in continual motion. The vertical rise and fall of the successive waves can be used to produce energy. The underlying principle is quite simple. Take a meter stick and attach a magnetic needle on its one end.

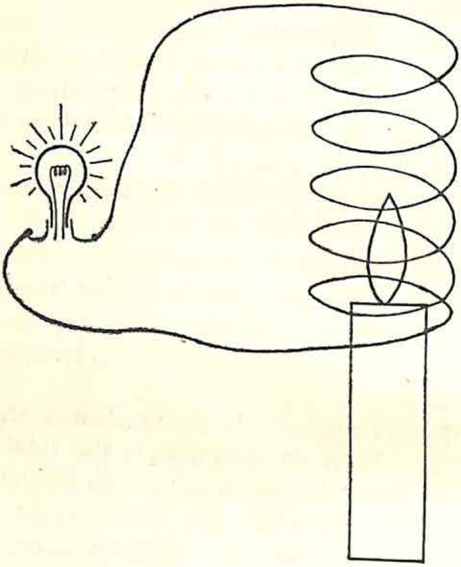

Fig. 7

Waves can move the scale up and down to generate electricity

Also take a cylindrical coil and connect its two ends to a torch bulb. If the needle is made to move in and out of the coil by moving back and forth the scale, what do you observe? The bulb glows. Thus, if this meter scale is placed on the water surface of the ocean, with the rise and fall of the waves, the needle will make corresponding in and out movement resulting into a current. Since the wave motion is perpetual, ocean waves can be harnessed to give energy ceaselessly.

Several models for wave-activated turbine generators (WATC) have been tried in Japan and U.K. The most popular is Salter duck. (See figure 8) It consists of a very long, floating cylindrical spine and a series of 20 to 40 vanes or cames or ducks which bob up and down by the rolling action of the waves. Through non return valves these ducks convert the rolling motion and turn a turbine. Other models like H.R.S. rectifier, oscillating water column, raft converter, duck, flexible bag, clam and others have also been tried out in U.K. However, each unit generates a very small quantity of electricity. Also, the cost is high. Multiple WATC designs proposed recently may probably reduce the cost and appear to be quite promising. In India, the National Institute of Oceanography is trying to develop wave-powered oscillatory system.

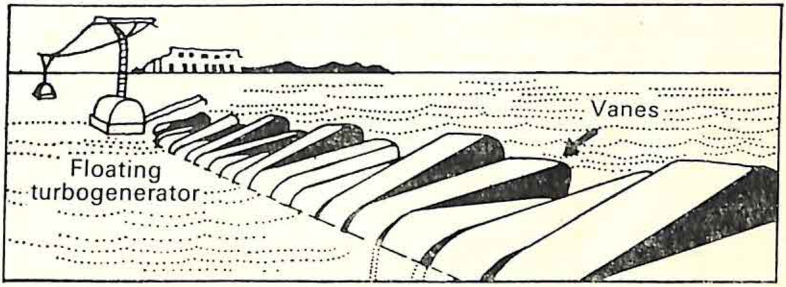

Fig 8.
Wave activated turbime generators

Energy from OTEC plants

One of the most talked about methods these days for extracting energy from the ocean is 'Ocean thermal energy conversion (OTEC).' The basic principle was laid down as long back as 1881 by a French scientist Arsened' Arsonval. It is well known that the sun heats the ocean and thus the energy is stored up in the top most layers. As we go below the surface, the temperature drops. To make use of this temperature difference, a fluid having low boiling point, *e.g.* ammonia or propane is pumped into a close tube placed in the warm water zone. The fluid gets vaporised by the heat of warm water. The vapour is allowed to expand through a turbine which can run a generator. The vapour leaving the turbine is channelled into a condenser located in the low

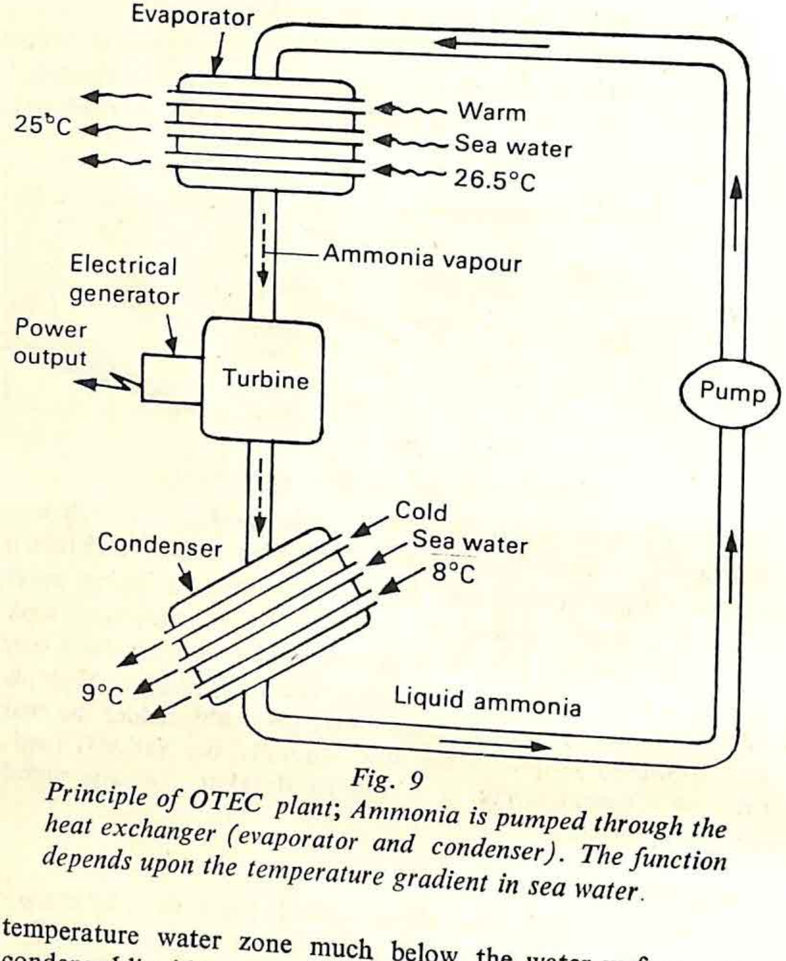

Fig. 9
Principle of OTEC plant; Ammonia is pumped through the heat exchanger (evaporator and condenser). The function depends upon the temperature gradient in sea water.

temperature water zone much below the water surface. The condensed liquid is pumped into a boiler evaporator to start the cycle afresh.

OTEC plants can thus supply an endless energy as the temperature difference is maintained between the top layers and cold water at lower depths due to solar radiation at no cost to us. Based on the above principle, George Claude built a small OTEC plant in Matanzas Bay, Cuba in 1930 but due to other sources of energy easily available at that time, scientists did not pay much attention towards the realization of such plants in practice. In late 1960's two Americans, J. Hilbert Anderson and his son James have considerably improved upon Claude's model.

It is evident that suitable temperature gradients are necessary to run such plants. Fortunately Indian waters in Arabian sea and Bay of Bengal are the suitable locations as is clear from the sea temperature profiles shown below. (Fig. 10) Tamil Nadu Electricity Board (TNEB) has initiated action in the direction of

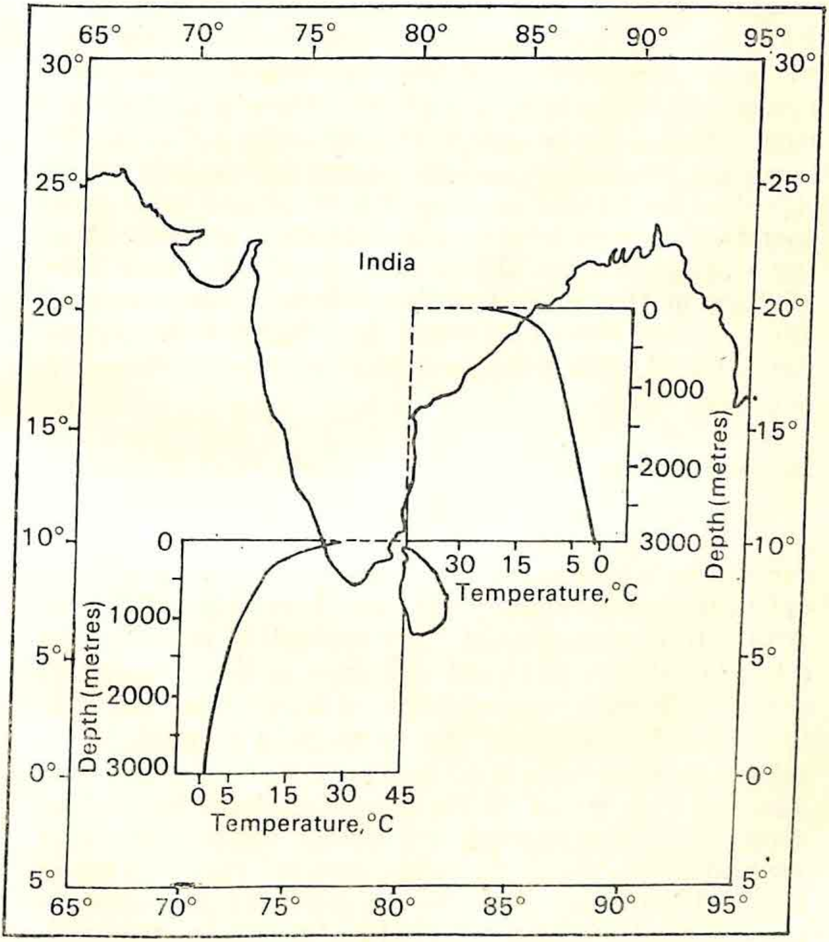

Fig. 10

Temperature profiles in Arabian sea and Bay of Bengal

the preparation of OTEC plants near Kulasekhara-pattinam, a small port in Tirunelveli district for generating 25 MW power. It is estimated that Tamil Nadu coast alone could sustain OTEC plants of 10,000 MW capacity.

According to the present estimates, OTEC power will be cheaper than coal based thermal plants. However, the main problem associated with OTEC plants is of choosing the suitable nature of heat exchanger as the metal is known to be toxic to marine life. There is also the possibility of the destruction of marine fauna causing imbalance in food chain and ecology around oceans. Corrosion can also cause leakages together with fouling (formation of slimy layers by marine organisms clinging to the surface of heat exchanger) which will require suitable cleaning methods. Above all, the cold water pipes through which the sea water will be pumped from deep layers will have to be very long and large in diameter. It is estimated that for a 250 MW plants, the effective water flow will be about one and a half million litres per second—comparable to average flow of the largest rivers in the world. Nevertheless, OTEC plants hold a good future as a renewable source of energy.

Energy from seaweeds

Some scientists think that the seaweeds which convert solar energy by photosynthesis (Bio-conversion) can also be valuable source of fuels, food and industrial products. Rapidly growing and easily harvestable is kelp (Ecklonia, Laminaria and Macrocystis). It is a giant, flat and tough seaweed. It grows upto 20 ft long in Atlantic Coast and still more in Pacific ocean. It grows best in warm, sunny climates. It has no roots and looks like a long brown ribbon. For commercial purposes, kelp is cultured on nylon ropes in the open ocean or in coastal waters. These are then moved to the processing plant where without damaging the plant, seaweeds are clipped. Mother plants are returned to the ocean for further growth. Each rope can be harvested four times a year. In the processing plant seaweeds are converted into methane, food and fertilisers. Work is in progress in U.S.A. to farm kelp in deep ocean waters and also to change kelp into oil, gasoline and cooking and heating gas.

The main problem with this bio-conversion process is getting enough of the seaweed. One way is to farm kelp first in suitable ocean waters. In tropical waters, kelp is not found. In Indian conditions 'Sargassum', a warm water seaweed is thought to be suitable for bio-conversion. Also, the work is in progress for cultivating algae at sea in special lagoons which could also provide an alternative source of energy.

Besides the above techniques, studies have been carried out, *e.g.* in Sweden to make use of salinity gradients to produce electricity. The basic principle is that if a semi-permeable membrane is placed between two solutions of different concentrations, the migration of ions takes place till the two concentrations are equal. This movement of ions produces electricity. It is not yet clear if the process could be used to generate sufficient electricity.

There have also been the attempts to produce power from ocean current but the problem is that of low energy density. Thus suitable means are yet to be explored to harness such renewable sources of energy.

4

Geothermal Energy

What a coincidence! We are living between two great sources of energy—energy obtainable from the sun and from the hot rocks beneath the earth's surface. Whenever there is any volcanic eruption, we come across the news that the lava boils and rises to great heights. Such a huge amount of energy in fact is

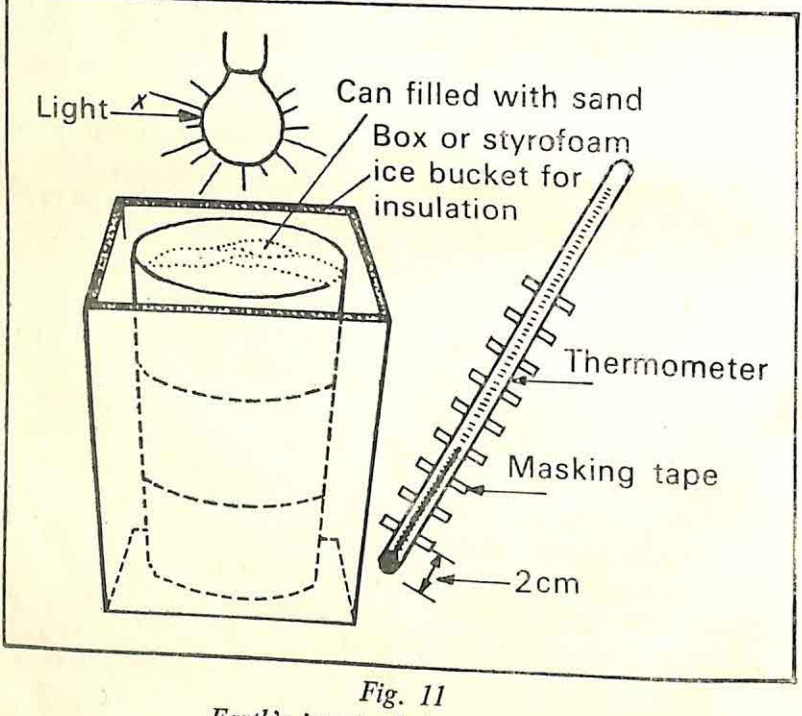

Fig. 11
Earth's interior behaves as above

available below the earth's surface. To have an idea, perform the following activity:

Collect sand in a container. Suspend a light bulb representing the sun. Heat the container for some time say 15-20 minutes. Switch on the light. Go on measuring the temperature of the sand at different depths with the help of a thermometer. What do you observe? Greater the depth, more is the temperature. Had you not known that the sand had been preheated, probably you might have expected the other way as the heat is coming from the light bulb. Similarly, though the sun is heating the earth's surface but as you go deep into the earth, the temperature increases. The earth has its own 'hot plate' in the form of very hot materials in and below the crust.

The following are the data taken from two wells drilled into the earth's crust.

Well I		Well II	
Depth (in Km.)	*Temperature (in °C)*	*Depth (in Metres)*	*Temperature (in °C)*
0	15	0	15
1	51	200	63
2	88	400	94
3	120	600	111
4	151	800	120
5	179	1000 (1 Km)	129
6	205	1200	134
7	232	1400	137
8	257	1600	139
		1800	142
		2000 (2 Km)	145

What do you observe? The temperature increases as we go deep but it is substantially more in the second well. Such regions are therefore preferable for getting energy from the earth and are known as 'geothermal areas'. The presence of hot springs and fountains of hot water called geysers or volcanos are considered as the manifestation of geothermal areas. In our country North Western Himalayas and the West coast are the

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areas where geothermal manifestations occur. Geothermal explorations are in progress in Puga in Jammu & Kashmir, in Parabati valley in Himachal Pradesh and along the West coast with the help of UNDP. Also, a cold storage and a power plant based on geothermal energy at Manikaran, Kullu District, H.P. are in testing phase. In countries like U.S.A., Australia, New Zealand and Italy, geothermal waters are used as a source of heat supply.

How is this huge amount of energy accumulated below the earth? Let us first see the structure of the earth. The earth is made up of a central core of a radius of about 1350 km. and is estimated to be at 4000—10,000°C. Surrounding this is a liquid core of about 2100 km thick. Between this and the earth crust, there is about 2900 km. thick mantle. In continental areas, the earth crust is on average 35 km. thick and 6 km. under the oceans. The interaction of temperature and pressure changes results in the melting of some rocks of upper mantle

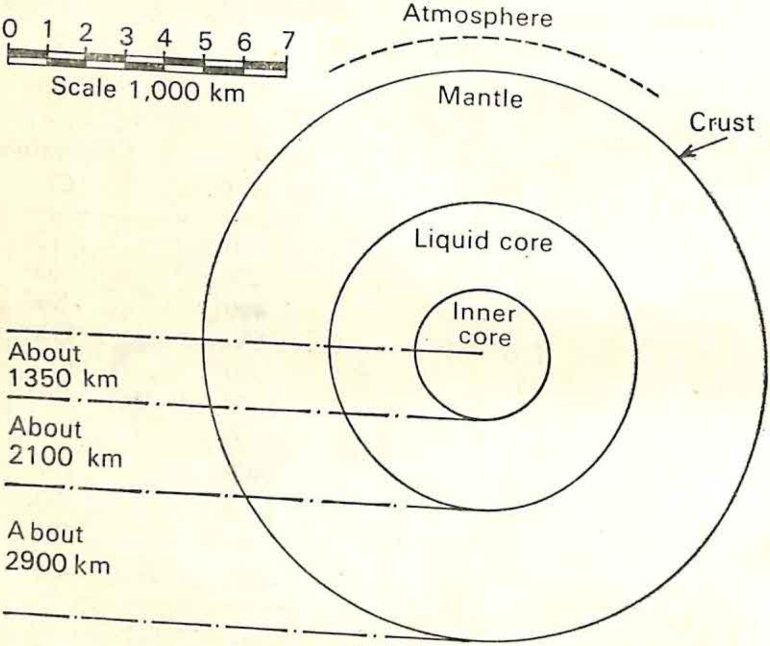


Fig. 12
Structure of the earth

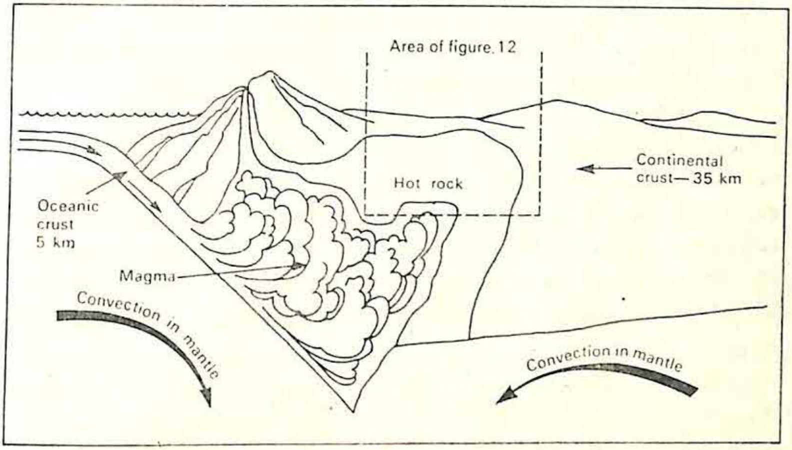


Fig. 13

and crust to form 'magma'. Magma thereby heats the rock about it. Above this impermeable rock there is a thick layer of

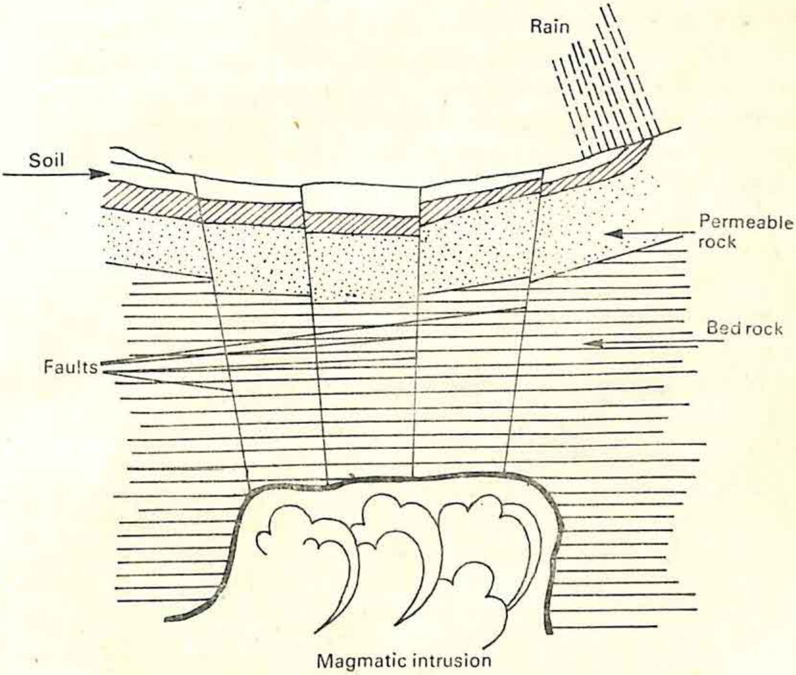


Fig. 14

permeable rock. This acts as an aquifer, *i.e.* a water bearing layer of rock. Rain water which flows into this area, gets heated due to the hot rock below. Above the aquifer there is more impermeable rock which prevents the escape of water and steam. Thus the principal source of heat for the geothermal field is the magma. But there are other heat sources inside the earth, *e.g.* the decay of radioactive elements in the crust, mantle and cores produce heat. There are chemical reactions happening in the crust which generate heat. Heat is also produced by friction when rock masses slide over each other. Thus, the 'hot

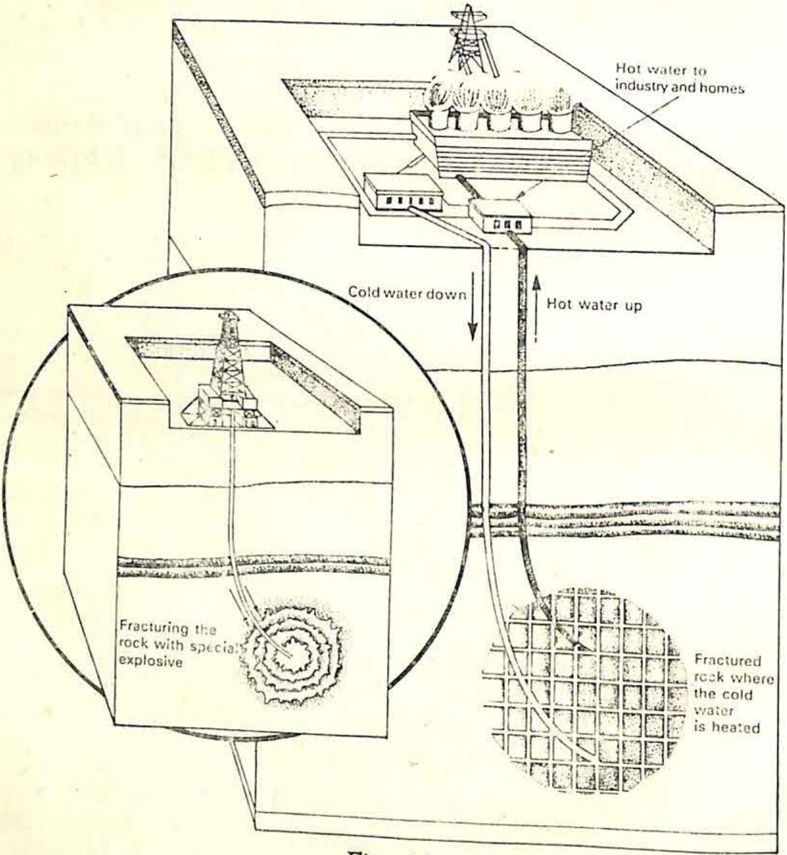

Hot water to industry and homes
Cold water down
Hot water up
Fracturing the rock with specials explosive
Fractured rock where the cold water is heated

Fig. 15
A geothermal energy plant

plate' of earth we talked earlier is heated due to a variety of sources available inside the earth.

How to harness this source of energy available in the earth's interior? The principle is simple but in practice quite complex. First, we locate a geothermal region. Then a bore is drilled through the soft rock near the earth's surface to the hot igneous granite rock far below. The inside rocks are fractured with suitable explosives so as to make space for large amount of water to be pumped into this region. Cold water is then sent through the above hole and the hot water is pumped back up to the surface through a second bore hole. The hot water or the steam produced can then be used in industries, heat exchangers, houses and offices.

The geothermal energy has so far not been fully tapped and is a promising extensive energy source for geothermal areas. Power plants will also take less time for their construction as compared to coal or nuclear plants. Technology has also been developed on small scale in individual cases. However, it is not commercially available. The main problems associated with geothermal energy plants are finding 'hot spots' of steam near earth's surface to avoid the need for complex plumbing. Steam or hot water may contain polluting minerals and thereby involving disposal problems and the earth's surface may cave in if the underground pressure is reduced. Also, as the thermal conductivity of the rock is very low, the supply of heat to hot water must involve large areas. This is a difficult proposition at a depth of 10-15 km. Suggestions like exploding atom bombs at these depths have been suggested. However, the realization of such a project is considered to be very costly besides the radio active hazards.

5

Nuclear Energy

The villain of energy is the dreaded nuclear energy. It has been under heavy criticism for a pretty long time ever since the bombs were dropped over Hiroshima and Nagasaki. However, in view of the tremendous potential this energy has and with no other non-conventional energy source proving to be that effective so far, while the fossil fuels are being exhausted at a rapid rate, more and more countries are trying to gain and enrich the technology used for harnessing nuclear energy. Our country is not lagging far behind in this direction.

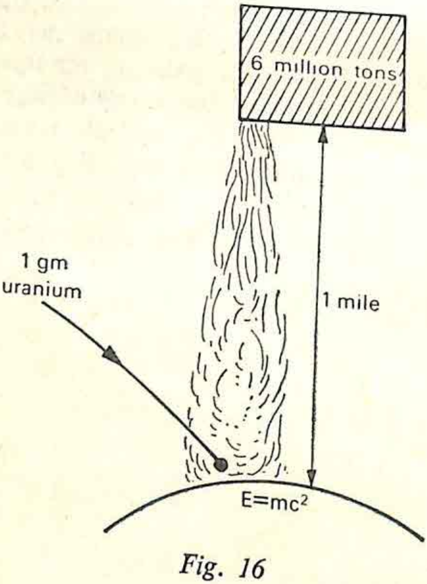


Fig. 16

Do you also know the enormous magnitude of this energy? You might be astonished to know that the transformation of 1 gm. of uranium gives that much energy that it can lift six million tons of weight for one mile into air or equivalent to 2.5 tons of coal as a source of electric power. The basic process used to achieve it is known as 'fission'. The same is carried out in a controlled way in the system known as nuclear or atomic reactor.

Fission

What is fission? Let us start from first principle. Every substance is composed of atoms. The atom in turn consists of a nucleus made up of a tight group of protons and neutrons. Each proton has a positive charge. Each Neutron has nearly the same mass as that of a proton but carries no charge. Some of the atoms have the same number of protons but a different number of neutrons. These are known as isotopes of the same element. For example uranium 235 and uranium 238, written as ${}_{92}U^{235}$ and ${}_{92}U^{238}$ respectively, are the isotopes of uranium. While each of them has 92 protons, the former has 143 neutrons and the latter, 146 neutrons. It is also found that the nuclei of some atoms are more stable than others, *e.g.* while atoms like iron 26, copper 29 and several others maintain their compactness, uranium 235, uranium 238 and other atoms decay, naturally known as radioactive decay. The decay is spontaneous and random whether they are in the form of ore, a compound or

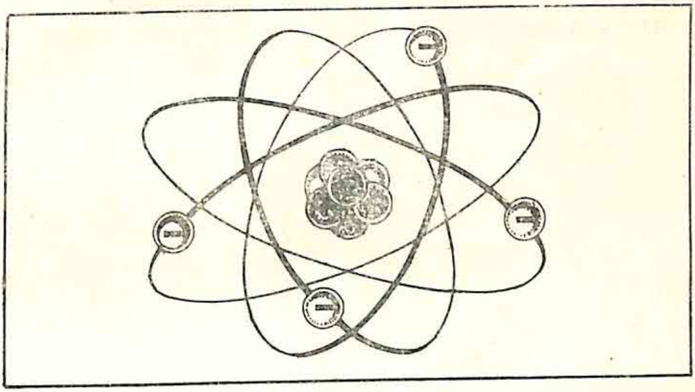


Fig. 17
Structure of an atom

pure metal. It is accompanied by a release of energy in accordance with the Einstein's relation $E=mc^2$ (where E represents the energy, m the mass and c the velocity of light) as the atoms continually and randomly break down and some of the mass is converted into energy. The energy appears partly as the kinetic energy given to the ionising radiation—alpha particles which come shooting out of their nuclei and partly as heat. About 100 tonnes of uranium produces one watt in a day by this process of natural radioactive decay.

Scientists have succeeded in splitting up the uranium nuclei by bombarding it with neutrons. When the nucleus of an atom of uranium 235 captures a neutron, it usually becomes so unstable that it breaks up into two nuclei (fragments) of about half the mass and charge and also emits two or three neutrons. In the whole process known as 'fission', uranium 235 atoms lose much more of their mass than they do so in the process of radioactive decay. Thus this lost mass results into liberating

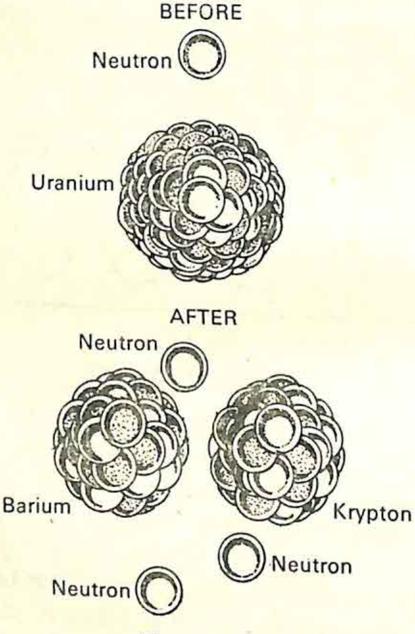


Fig. 18 (a)
Splitting of atoms by nuclear fission

far more energy. If one gram of uranium atoms is fissioned in a day, energy at the rate of 1000 kilowatts is produced. See how many times it is than that given out by natural radioactive decay!

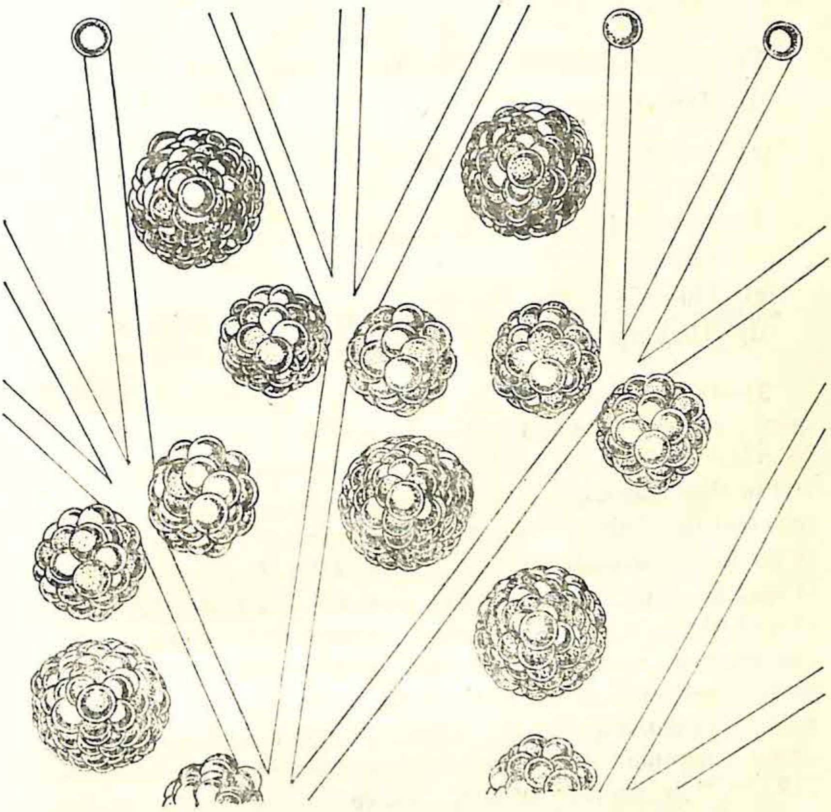


Fig. 18 (b)
Splitting of atoms by nuclear fission

Will the fission die out just after it breaks uranium 235 into its fission products including a tremendous release of energy? No. Though the fission still happens at random, every fission produces 2 or 3 neutrons. These neutrons, if not allowed to escape (because they have energy), act on other uranium atoms and result into more energy as well as further release of neutrons. This process leads to the building up of the fission. However, when there is a balance between the neutrons being formed and the neutrons being utilized in fission and in other absorptions, this forms a self-sustaining chain of reactions known as 'chain reaction'. This forms the basic principle of any atomic reactor producing energy. When this happens, the reactor is said to have gone 'critical'.

The main characteristics of an atomic reactor are:

(i) Type of fuel used:

(a) Natural uranium containing 99.28 per cent of Uranium 238 (${}_{92}U^{238}$) and 0.72 per cent of uranium 235(${}_{92}U^{235}$)

(b) Enriched uranium, containing more than 0.72 per cent of ${}_{92}U^{235}$

(c) Plutonium 239 (${}_{92}Pu^{239}$)

(d) Uranium 233 (${}_{92}U^{233}$)

The isotope U235 is easily fissionable. Sophisticated techniques, *e.g.* centrifuge and others are used to extract this isotope from the uranium ore. It is split by neutrons of any energy—fast or slow. Better it is, if the energy of neutrons is less. It is seen that the chain reaction in natural uranium dies out because of the loss of secondary neutrons. Thus if a mixture of isotopes is used in a nuclear reactor, the neutrons available should be slowed down. This will enable uranium 235 atoms in the mixture to easily capture these slow neutrons and make the chain reaction self-sustaining. Another fuel that can be used in the reactor is prepared when U^{238} after capturing a neutron forms an unstable neptunium 239 which further breaks up into plutonium 239. Pu^{239} is another suitable source in which chain reaction causing fission can be initiated. The fission of U^{238} always occurs with difficulty and only under the action of fast energy neutrons.

India has big deposits of Thorium mineral (monazite sand) in the coastal belt of Kerala State. Thorium 232 can be converted into uranium 233 to be used as nuclear fuel.

(ii) Neutron energy: The above discussion will indicate that the neutrons used are

(a) Low energy or thermal neutrons

(b) Intermediate energy neutrons

(c) High energy neutrons
depending upon the type of fuel used.

(iii) Moderator: In some reactors, the neutrons need to be slowed down to keep the chain reaction self-sustaining. Used for this purpose are the moderators. The common moderators are:

(a) Heavy water D_2O
(b) Graphite
(c) Beryllium oxide or Beryllium
(d) Water

(iv) Coolant: The energy produced in the reactor must be removed by circulating a coolant through the reactor. These are:

(a) Air, Co_2 or He
(b) Water or other suitable liquids.
(c) Liquid metal, *e.g.* that of Potassium—Sodium.

(v) Control rods: In the reactor fission takes place very fast. Thus neutron absorbing control rods made up of cadmium or boron steel are used to control the number of neutrons available for fission production. Some other rods are also there which automatically enter into any critical situation to stop the reaction and thus serve the purpose of 'safety fuse'.

(vi) Radiation shield: To withstand the pressure of the circulating coolant gas there are pressure vessels. Also to protect the workers from the neutrons and gamma radiation given off by uranium when its atoms split, there is a thick concrete shielding which absorbs them.

Based on the first principles, a number of reactors of different type were set up throughout the world (see the table given on next page) for experimental and research purposes initially. India too installed a few at Trombay known as Apsara, Zerlina, Canada India reactor and has commissioned recently the research reactor 'Dhruva'. As its consequence, nuclear power generation plants

Different Types of Reactors

	Thermal reactors			*Fast reactor*
	magnox power stations	steam generating heavy water reactor power station (SGHWR)	advanced gas cooled power stations (AGR)	protoype power station (PFR)
Fuel	uranium metal (0.7% U 235) in magnox alloy	uranium oxide (3% U 235) in zircaloy	uranium oxide (2.3% U 235) in stainless steel	mixed oxides of plutonium and uranium in stainless steel
Coolant (outlet temperature)	Carbon dioxide gas (400°C)	light water liquid (280°C).	carbon dioxide gas (650°C).	sodium liquid (560°C to 600°C).
Moderator	graphite	heavy water(D_20)	graphite	none needed

also came into existence. Our country took initiative in this direction in 1969 by setting up Tarapore power station with an installed capacity of 420 MW. Subsequently two units of 220 MW each were commissioned at Rajasthan Power Station near Kota.

Another generation of nuclear reactors known as 'fast breeder reactors' has come into existence as the manifestation of advances in nuclear technology. It is called fast because the neutrons are not slowed down or moderated as they are by heavy water in thermal power reactors. In fact, it does away with the use of moderator. It is called breeder because it has the ability to breed, *i.e.* to create more fissionable material than it consumes. The fast breeder is therefore the *Kamdhenu* of nuclear technology. By now only six countries, *viz.* France, U.S.S.R., U.K., West Germany, U.S.A. and Japan had this technology. India entered this select club on October 18, 1985 when the fast breeder reactor installed at Kalpakkam near Madras went critical. The development of a plutonium-uranium carbide fuel for this reactor is the major contribution of Bhaba Atomic Energy Research Centre. This breeder reactor may require as little as 1.3 tonnes of uranium per million KW year of power compared to 171 tonnes required by present water cooled reactors. See figures 19 (a) to (d) for different types of reactors.

Nuclear energy is therefore a ray of hope as the future promising energy source. Besides, the power obtained from these plants is cheaper than from coal plants. Abundant supply of uranium is also available. All the more, fast reactors breed more fuel than they burn. Therefore, the fuel is theoretically inexhaustible. Nevertheless, there are economical, political and technological problems associated with the use of nuclear energy. Technology is limited to few countries. There are arbitrary and stringent conditions in terms of non-proliferation treaty and a threat of sabotage. Extremely tight nuclear safeguards are absolutely essential. Otherwise a slight leakage or carelessness may be fatal to the human beings due to radioactive fall out. Nuclear plants are expensive and time consuming to build. Lastly, there are problems of how to dispose of the radioactive wastes as well.

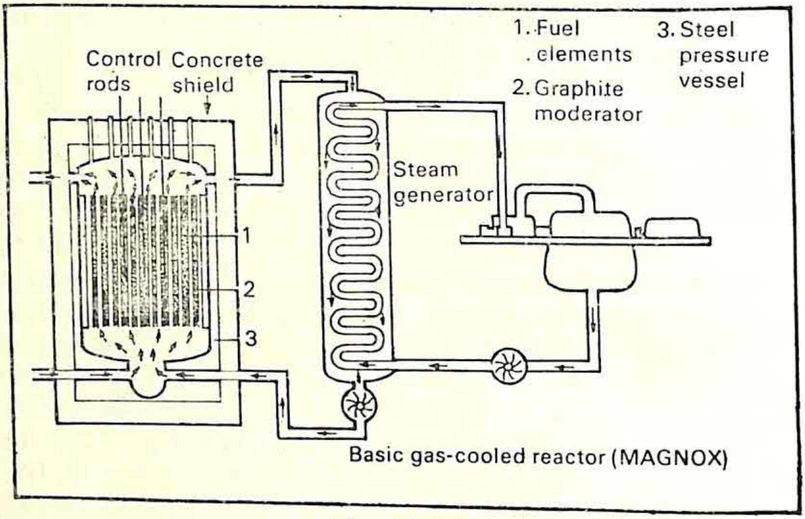


Fig. 19 (a)

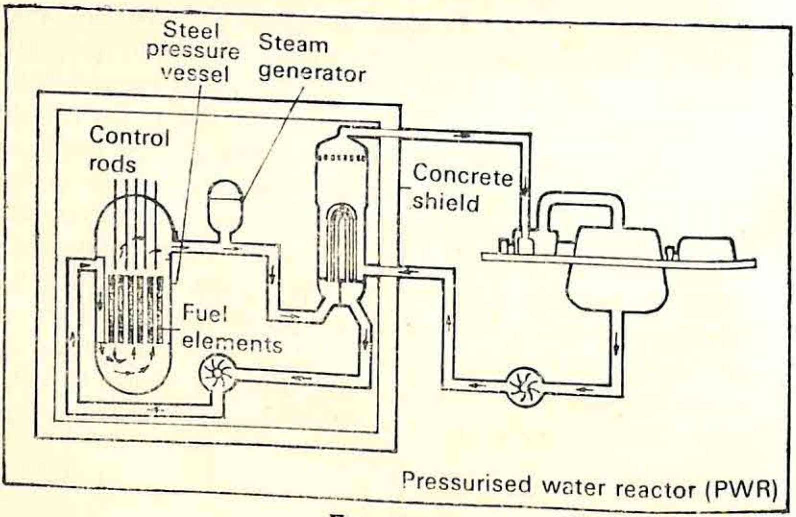


Fig. 19 (b)

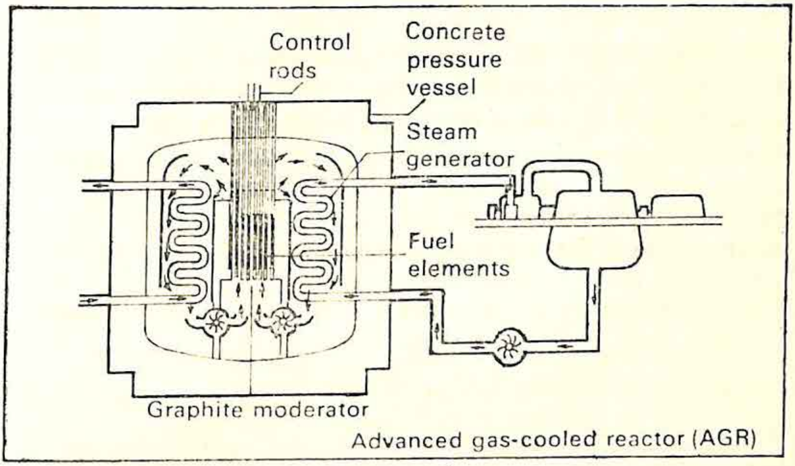


Fig. 19 (c)

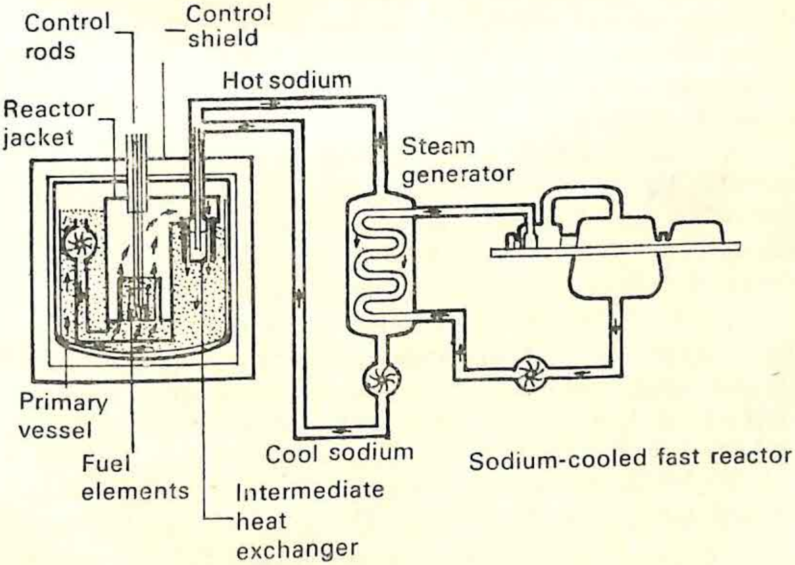


Fig. 19 (d)

Fusion

Scientists are venturing to manufacture a 'sun on earth'. Yes, it is correct. Don't be surprised. After all, what is happening in the sun? Hydrogen atoms are moving with such tremendous speeds because of enormous temperatures that when they collide, they fuse with each other. It happens not in one step but a series of reactions takes place.

Have a look at the following reactions:

$${}_1H^1+{}_1H^1\rightarrow{}_1D^2+\beta^2+9\ \text{Mev}$$
$${}_1H^1+{}_1D^2\rightarrow{}_2He^3+\gamma+5.5\ \text{Mev}$$
$${}_2He^3+{}_2He^3\rightarrow{}_2He^4+2\,{}_1H^1+2.8\ \text{Mev}$$

The symbols ${}_1H^1$ and ${}_1D^2$ stand here for nuclei of hydrogen and its known isotope as deuterium (because of high temperature, electrons are already stripped off and ${}_1H^1$ contains 1 proton while ${}_1D^2$ contains one proton and 1 neutron). Similarly, ${}_2He^3$ and He^4 are the isotopes of helium containing 2 protons and one neutron and 2 protons and 2 neutrons respectively, β^2 and γ are a positive beta particle known as positron and gamma radiation respectively. The number of Mev in each equation indicates the energy released (popularly known as thermonuclear energy) by the fusion of a pair of nuclei into the heavier ones. Since these reactions take place at very high temperatures, they are called 'thermonuclear reactions'.

As a result of the above reactions, in the sun's interior every second 564 million tons of hydrogen is being converted into 560 million tons of helium and the remaining 4 million tons change into energy in accordance with the relation $E=mc^2$ given above. How huge this natural atomic power plant is!

Do you note what is the difference in the process fission, you knew earlier and the present process of fusion. While the former involves splitting of heavy atoms, the latter is the joining of light atoms into heavier ones. Both the processes, however, release tremendous amount of energy.

To have the above reactions, it requires several steps and a great deal of time in laboratories. On earth, however, we have a cheap and abundant source of deuterium. Such a source is the oceans and seas of the world. They contain about 0.015

per cent deuterium amounting to 10^{15} tons. Scientists are therefore striving for producing thermonuclear energy with either of the following thermonuclear reactions:

$${}_1D^2 + {}_1D^2 \rightarrow {}_2He^3 + {}_0n^1 + 3.3\text{Mev}$$
$${}_1D^2 + {}_1D^2 \rightarrow {}_1T^3 + {}_1H^1 + 4.0\text{Mev}$$

n indicates the neutron. ${}_1T^3$ is another isotope of hydrogen having one proton and two neutrons. In case, the products of the above reactions are not allowed to escape, it is then possible to have the following reactions further:

$${}_1D^2 + {}_1T^3 \rightarrow {}_2He^4 + {}_0n^1 + 17.6\ \text{Mev}$$
$${}_1D^2 + {}_2He^3 \rightarrow {}_2He^4 + {}_1H^1 + 18.3\ \text{Mev}$$

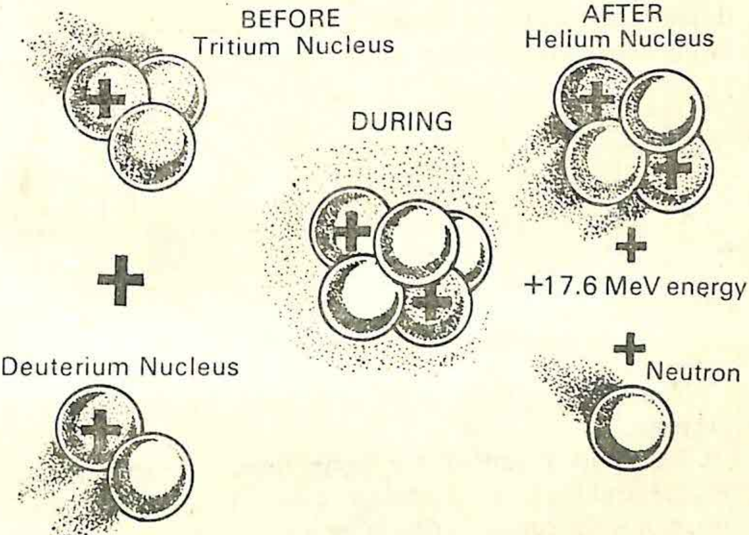


Fig. 20

Compare the energy per unit weight of the fuel released by fusion reaction here to the energy released by disintegration, *i.e.* fission of heavy nuclei of uranium. The quantum of heat evolved by the reaction from 1 kg of gaseous deuterium is equivalent to 10 thousand tons of coal on combustion.

The speed of the atomic particles, before they collide, should be enormous to have the above reactions. This is made possible by heating the particles to hundred million degrees. Much below this temperature, the atoms are already stripped of their electrons. Thus they form a mixture of positively charged ions and electrons known as 'plasma' and conduct electricity. If we pass a high electric current through this plasma, the temperature will rise. However, with the rise in temperature, the resistance of the plasma decreases and it conducts electricity better. This form of heating is therefore not quite effective. Other mechanisms known as turbulent heating, injection of high energy particles into the plasma and others are used to further raise the temperature for attaining fusion reactions.

Such reactions happening in a controlled fashion and on economical basis as well are therefore the future hope for the scientists. We will then be having a generation of thermonuclear fusion reactors all over the world. At present, the scientists are facing numerous difficulties in this venture.

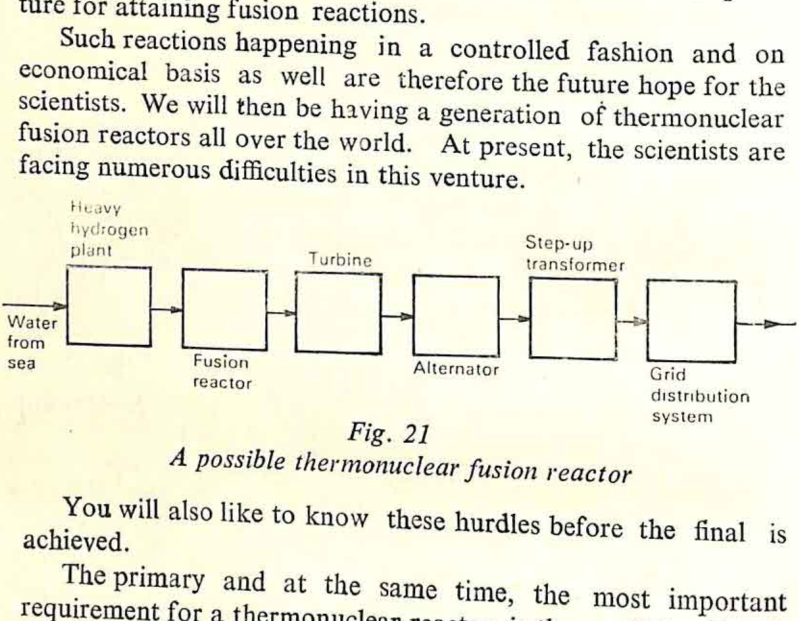


Fig. 21
A possible thermonuclear fusion reactor

You will also like to know these hurdles before the final is achieved.

The primary and at the same time, the most important requirement for a thermonuclear reactor, is the condition $\bar{C} > A$ where n is the concentration of electrons or nuclei in the plasma and $\bar{C}$ is the confinement time of plasma. 'A' characterizes the nuclear fuel. For denterium-denterium reactions $A \sim 10^{16}\ \text{cm}^{-3}$ second and for a mixture containing equal amount of deuterium-tritium $A \sim 10^{14}\ \text{cm}^{-3}$ second, *i.e.* at least the following inequality known as Lawson Criterion is to be satisfied:

$$n\bar{C} > 10^{14}\ \text{cm}^{-3}\ \text{second.}$$

Can we increase n to any value in order to satisfy this condition? No, there are a lot of problems. We have to raise the plasma temperature considerably. Deuterium-tritium mixture burns fast enough only at $T > 10^8$ °K and then the reacting nuclei having the same charge get enough energy to fuse despite their electro-static repulsion. At the same time, because of enormous pressure, there is a difficulty for providing a vessel which can contain the plasma. A vessel made of any material may either melt or cool down the plasma or contaminate it. Confinement of the plasma making use of magnetic fields is now-a-days the choice as is being done in the experimental reactors known as Tokamaks in U.S.A., U.S.S.R., U.K., and a few other countries.

The Tokamak system makes use of a pair of magnetic fields to hold the plasma in the shape of a torous. The fields are

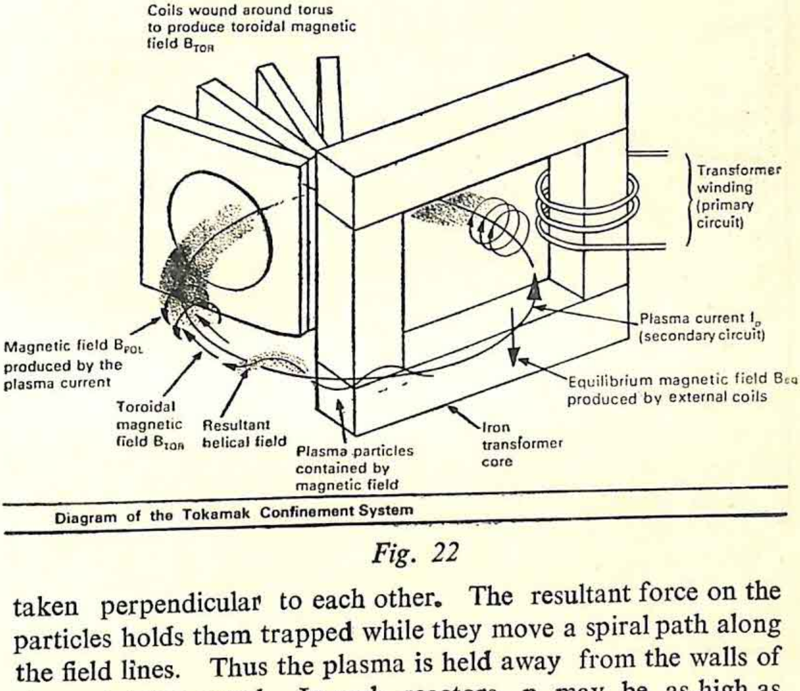

Coils wound around torus to produce toroidal magnetic field B_{TOR}
Transformer winding (primary circuit)
Plasma current I_p (secondary circuit)
Magnetic field B_{POL} produced by the plasma current
Equilibrium magnetic field B_{EQ} produced by external coils
Toroidal magnetic field B_{TOR}
Resultant helical field
Plasma particles contained by magnetic field
Iron transformer core

Diagram of the Tokamak Confinement System

Fig. 22

taken perpendicular to each other. The resultant force on the particles holds them trapped while they move a spiral path along the field lines. Thus the plasma is held away from the walls of the containing vessel. In such reactors, n may be as high as 3×10^{13} cm^{-3} and $\bar{C} \sim 0.1$ second while the temperature $T \simeq 10^7$ °K. To satisfy Lawson Criterion, $n\bar{C}$ is therefore to be increased about 30 times or so. Another problem with these reactors is that the heat conduction to the walls is still very high. n can't be further high otherwise magnetic walls will be destroyed.

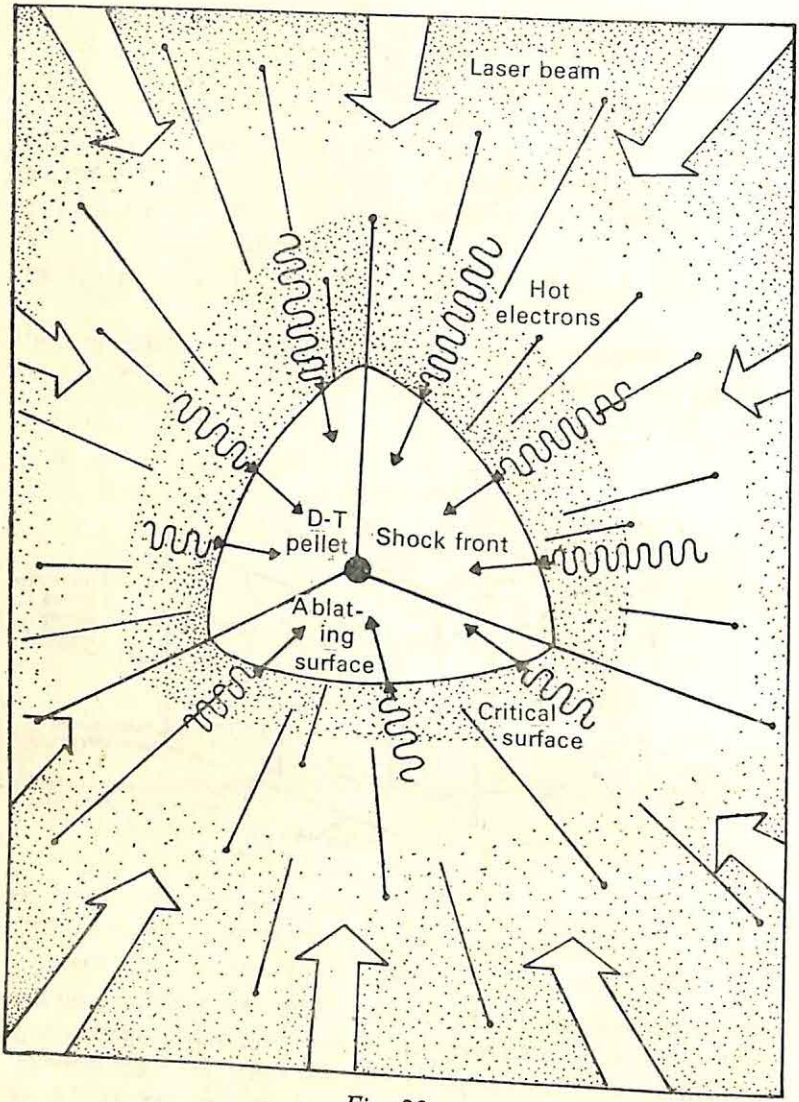


Fig. 23

Nuclear Fusion by Laser Implosion

Laser beams heat the pellet of deuterium-tritium fuel. Light is absorbed at the critical surface. Hot electrons, travel inward and thereby heating and ablating the surface of the fuel pellet.

Energized matter shoots outward but the reaction from this force acts inwards imploding the remainder of the matter.

Another technique known as Laser thermonuclear fusion is also being tried out now-a-days. In such type of reactors the concentration may be as high as 10^{22} cm—^{3} providing enough scope for satisfying Lawson Criterion. However, a laser light pulse of proper duration having the energy as high as 10^4—10^5 Joules, a suitable shape of the pulse thereby checking the particle from being scattered out and the demanding high efficiency of the lasers are still the problems to be tackled successfully.

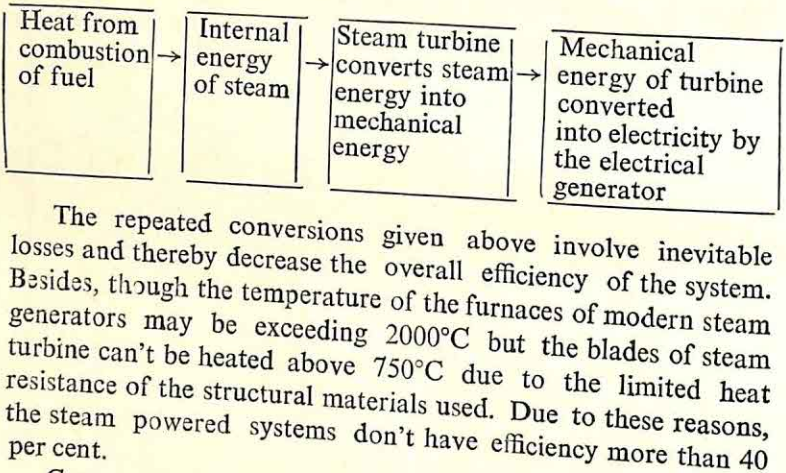
Recently, physicists at the Australian National University have developed a new device to contain the reaction of heated hydrogen gas in the fusion reactor known as 'heliac'. This uses a plasma ring formed into a heliac and achieves the same result as in Tokamak but without the large plasma current.

Immense difficulties are therefore yet to be overcome. But there is every hope that some day we will be having thermonuclear fusion reactors which will provide a long lasting solution to the energy crisis for the benefit of the present and the coming generations.

6

From Heat to Electricity

The most convenient form of using energy is electricity. Heat is also a form of energy. How can you get electricity from heat? Well, you may mention electrical generators moved by steam turbine and producing electricity. What are the stages of transformation in such a system?


Heat from combustion of fuel
Internal energy of steam
Steam turbine converts steam energy into mechanical energy
Mechanical energy of turbine converted into electricity by the electrical generator

The repeated conversions given above involve inevitable losses and thereby decrease the overall efficiency of the system. Besides, though the temperature of the furnaces of modern steam generators may be exceeding 2000°C but the blades of steam turbine can't be heated above 750°C due to the limited heat resistance of the structural materials used. Due to these reasons, the steam powered systems don't have efficiency more than 40 per cent.

Can we cut short the above energy conversion stages and convert heat directly into electricity? Yes, it has been made possible so far by three types of systems, *viz*. magneto-hydrodynamic popularly known as MHD, thermoelectric and thermionic devices.

Magneto-hydrodynamic generator: Take a conductor. Join its ends with a Galvenometer. Move the conductor in between

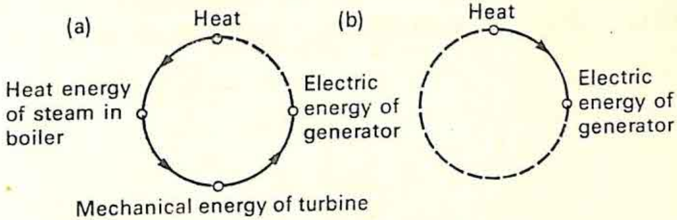

(a)
Heat
Heat energy of steam in boiler
Electric energy of generator
Mechanical energy of turbine
(b)
Heat
Electric energy of generator

Fig. 24

A comparison of steam operated with direct conversion electricity plant.

the two pole pieces with north and south poles facing each other. What do you observe. Why does the Galvenometer show deflection? Faraday attributed it to an e.m.f. induced in the conductor. Such an e.m.f. is induced whether the conductor is solid, liquid or gaseous.

Kelvin prepared a generator by passing a conducting liquid in between the two plates placed in earth's magnetic field. This laid the foundation of MHD generation. He took two metallic plates (2 in figure 25) and immersed them in salt water flowing in the river. The plates were located parallel to the river banks. It was seen that the current in conductors 1 was proportional to the density of earth's magnetic field and to the velocity of the

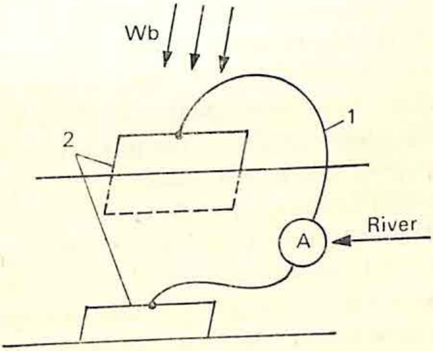


Fig 25

sea water stream in the river. When the water in the river reversed its direction of flow, same change was observed in the direction of current flowing in the conductors in between the plates. In MHD generator, an ionized gas (a gas when sufficiently heated loses its one or more electrons and is known as ionized) is passed between the metal plates situated in a magnetic

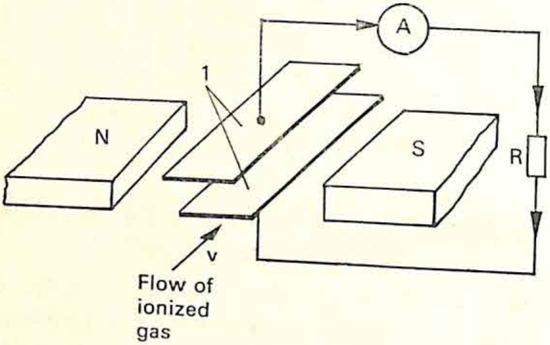


Fig. 26

field. In accordance with the Faraday's law of electromagnetic induction, an e.m.f. is induced and causes the current to flow in the external circuit. How does it really happen?

When a gas is heated sufficiently (say upto 3000°C), its internal energy increases and becomes electrically conducting. Thus on passing such a gas through MHD ducts, the gas expands and its heat energy is directly converted into electricity. Though the efficiency of MHD system is higher (about 60 per cent) than steam powered generators, but the problem is regarding the components carrying ionized gases, *i.e.* the chamber, ducts, nozzle, etc., can't be kept from losing strength at high temperatures.

An MHD powered plant produces 25 MW of electricity in U.S.S.R. Our country is also in the process of constructing one MHD power pilot plant of 6 MW capacity in Tiruchirapalli, Tamil Nadu with Soviet cooperation.

Since MHD systems can't be operated at lower temperatures, because the gas becomes electrically conducting only at high temperatures, attempts are being made to prepare MHD plants alongwith normal steam operation plants.

MHD power generating plants using plasma have shown much promise for the future. It is for this reason that different types of schemes are being tried out. MHD generators using nuclear reactors for heating the gas so that the latter becomes ionized and conducting for use in the plants are in the offing.

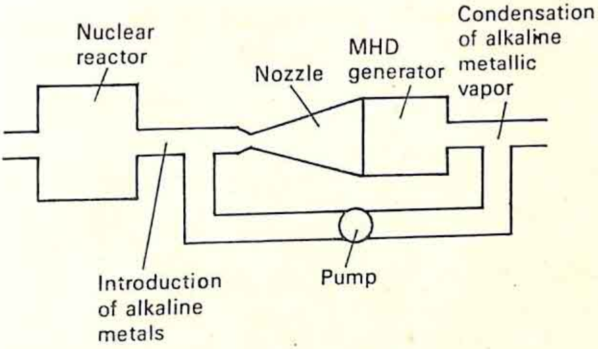

Nuclear reactor
Nozzle
MHD generator
Condensation of alkaline metallic vapor
Introduction of alkaline metals
Pump

Fig. 27

MHD systems using chamber type reactors have been suggested. A mixture of helium and uranium is fed into a chamber

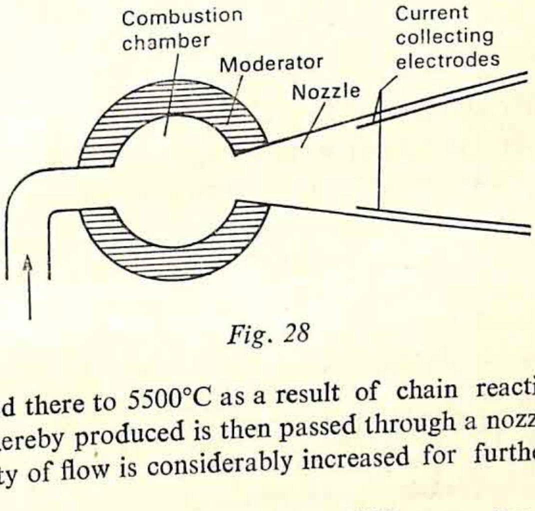


Fig. 28

and heated there to 5500°C as a result of chain reaction. The plasma thereby produced is then passed through a nozzle so that the velocity of flow is considerably increased for further operation.

Another scheme suggested for MHD generator is using plasma wave to produce a-c power. A chamber contains such an amount of radioactive gas that the chain reaction is not possible so long as the gas is uniformly distributed. To start the reaction, the gas is compressed. A shock wave is produced followed by the flow of plasma. At the opposite end of the chamber, another chain reaction takes place and the plasma comes back to its original state. Thus, in view of high efficiency of MHD power generators, many countries including ours are trying to find the most suitable and efficient scheme for the future.

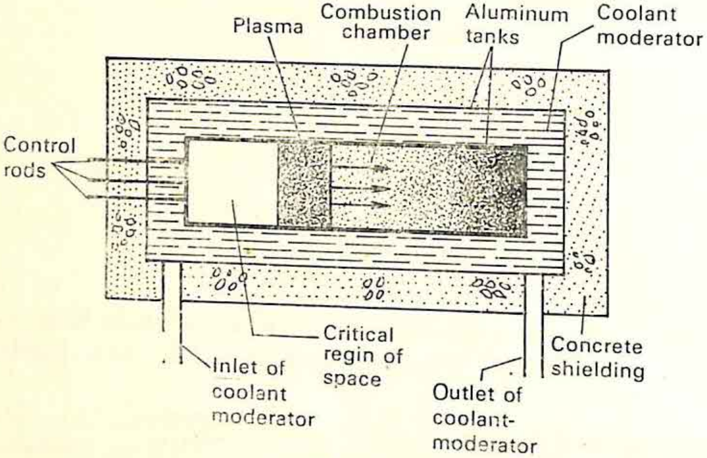


Fig. 29

Thermal Converters. Take two metallic wires, say, iron and copper. Make two junctions as shown in figure 30 and connect them with a galvenometer. If you heat one junction and keep

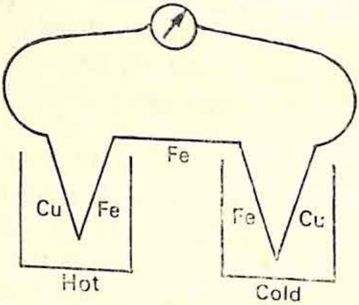


Fig. 30

the other junction cold, what happens? Galvenometer shows deflection indicating that a current starts flowing in the circuit, e.m.f. thus generated is known as Thermo e.m.f. and the arrangement—Thermocouple. German physicist Seeback observed this effect for the first time. Based on this principle, a direct conversion of heat into electricity takes place. Systems used for this purpose are known as 'Thermal converters'. It is seen from experiments that e.m.f. in a Thermocouple depends upon the materials used and the temperature of the hot and cold junctions, *i.e.*

$$E = \alpha \, (T_h - T_c)$$

where α is thermoelectric coefficient dependent upon the material and T_h & T_c are temperatures of hot and cold junctions respectively.

How will you use the above principle to construct thermal converters which give higher voltage output? Using a number of thermocouples in series and by keeping alternate junction hot and cold in such a way that the individual e.m.f. thus generated add and give a higher output. Moses Pauli did the same and called this arrangement—thermopile. However, as the internal resistance grows with the increased number of series connected thermocouples, this sets an upper limit on the power output. As a result efficiency is quite low.

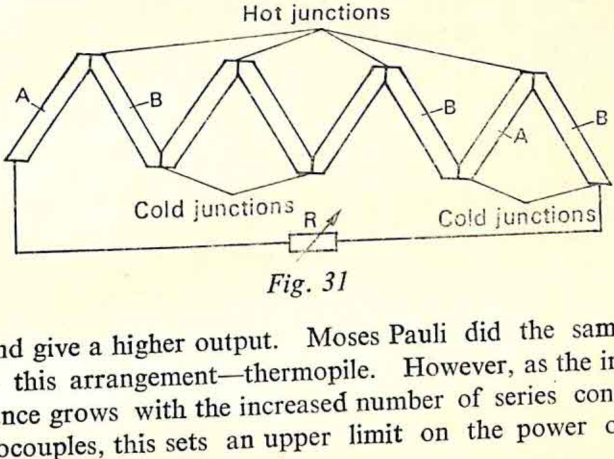


Fig. 31

With the incoming of semiconductors, solid state thermal converters have been prepared. Like electrons as the carriers in metals, a semiconductor has electrons or holes (equivalent to positive charge) as the charge carriers and is respectively known as n-type or p-type.

A solid state thermal converter consists of both n-type and p-type semiconductors. Charge carriers move from hot to cold junction in the two halves as shown in the figure. The e.m.f. thus generated depends upon the difference of temperature of the two junctions as in metals. However, the e.m.f. may be about 40 times higher than in thermocouples made up of metals. The direction of the flow of current depends upon the flow of

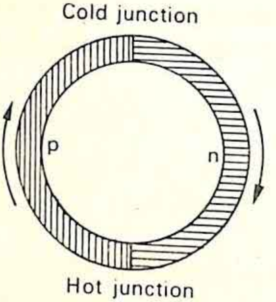


Fig. 32
A solid state thermal converter

positive charge carriers. The currents in the halves of semiconductor flow in the same direction. For obtaining a higher output a number of thermocouples in series, each consisting of both n and p type semiconductor may be used.

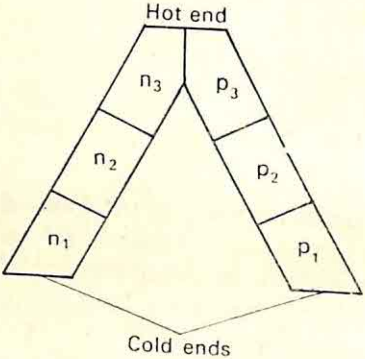


Fig. 33

Modern thermal converters make use of materials like tellurides and selenides. Efficiency may be about 10 per cent. The difficulty in perfecting solid state thermal converters the existing semiconductors are capable of withstanding a temperature of 535°C. Studies are being carried out to produce semiconductors operable at higher temperatures. Also nuclear-fuelled thermal converters are being prepared. In U.S.S.R. one of this kind named 'Romashka' has been built and has a power output of 500 W. In such thermal converters, temperature of the hot junction is raised by the heat obtained in reactors by

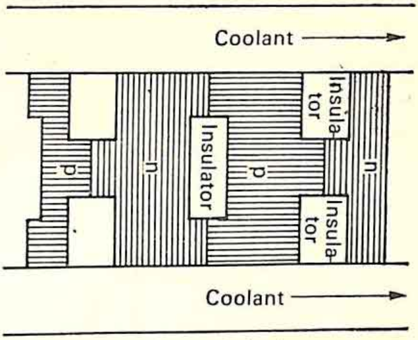


Fig. 34 (a)

splitting nuclei of heavy elements. A thermopile can also be built up from thermoelectric elements made of fissionable material having the properties of semiconductor, *e.g.* uranium and thoriumsulphides.

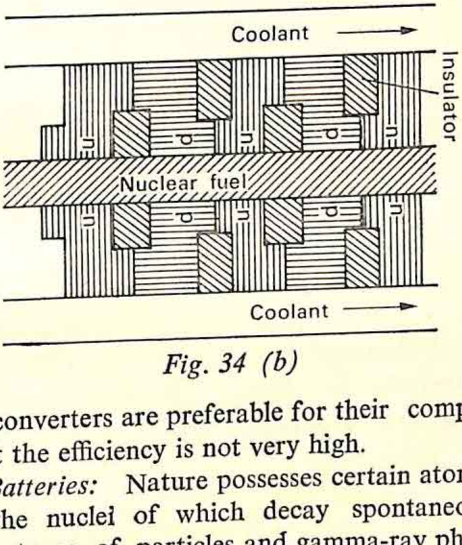


Fig. 34 (b)

Thermal converters are preferable for their compactness and reliability but the efficiency is not very high.

Nuclear Batteries: Nature possesses certain atoms known as radioactive the nuclei of which decay spontaneously. They emit various types of particles and gamma-ray photons. The kinetic energy of these particles is absorbed by a medium surrounding the radioactive substance and converted into heat. The heat produced may be used to generate electricity making use of thermocouples as described in the earlier section. These systems which convert the energy of natural radioactive decay into electricity are known as nuclear batteries. Also when they employ thermoelectric elements, they are known as thermojunction batteries.

Nuclear batteries have high operating reliability, compactness and long life. Efficiency varies from 3 to 5 per cent. These batteries are considered to be of great use in space-craft.

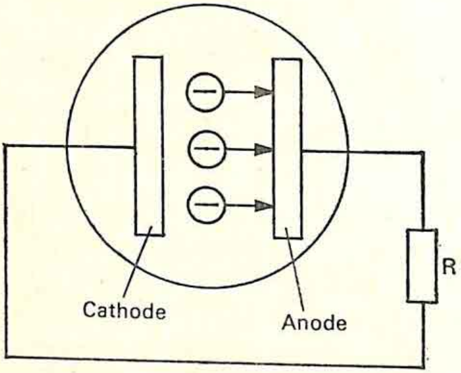


Fig. 35

Thermionic Converters: What happens when you heat a liquid say water. It boils and then starts evaporating. Why? The liquid atoms initially are closely packed as if they attract each other. On being heated, as the atoms gain energy, the force of attraction is overcome and the atoms start leaving the liquid surface. Similarly when a metal is heated under suitable conditions, the electrons of its atoms in the outermost orbit known as valence electrons or free electrons leave the surface. This phenomenon is known as thermionic emission. The electrons ejected out may be manipulated to give current.

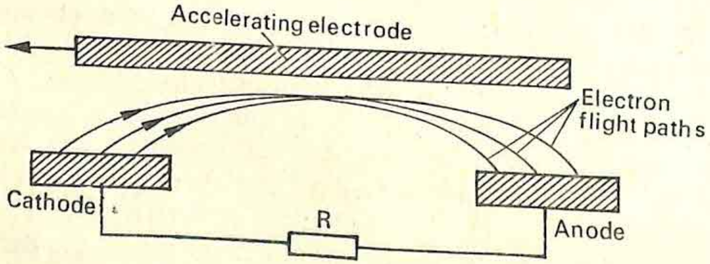


Fig. 36

Use is made of the above principle for power generation by preparing thermionic converters. Like a two electrode vacuum tube known as diode valve, having a cathode and anode, the thermionic converters are constructed. The electrons leaving the cathode are accelerated with the help of an electrode maintained at a high positive potential. The magnetic field directs them towards an anode where they are collected to give current. The cathode may be heated using nuclear fuel. The efficiency of such converters is about 15 per cent. It is estimated that it can be raised to 40 per cent with suitable modifications.

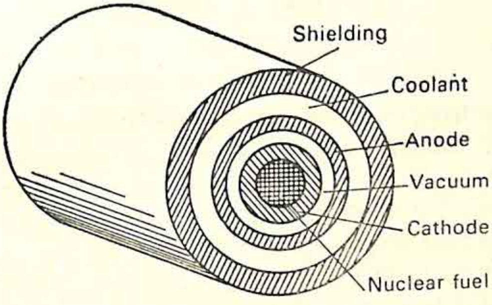


Fig. 37

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7

Fuel Cells

You must have come across the news that the first Gemini spacecraft in 1965 and Apollo spacecrafts contained hydrogen-oxygen fuel cells as a part of its power equipment. What is special about these cells as compared to other conventional fuels in view of the fact that the load to be carried by spacecraft be minimum? To know it, let us see how does a fuel cell work?

The cell consists of two electrically conducting porous plates (2 & 4) which serve as electrodes and are fixed parallel to each other. The space between the plates is filled with an electrolyte, *e.g.* Potassium hydroxide in water. Liquid penetrates into the electrodes but can't pass right through them. On the left of one electrode is hydrogen to be used as fuel and on the right of the other oxygen to be used as an oxidant. The gases penetrate

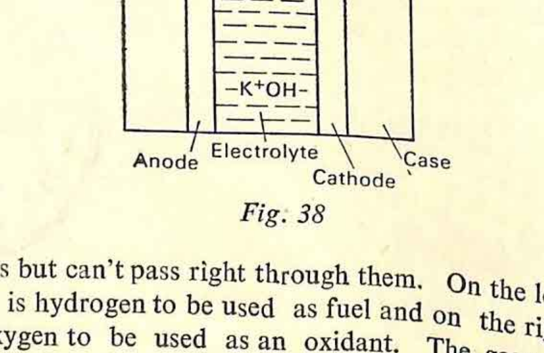


Fig. 38

partly into the electrodes but because of the presence of the electrolyte, they are checked from passing right through. When some of these gases are dissolved in the electrolyte, they diffuse through it and reach the wetted surface of the electrode on its side of the cell. As a result, while the surface of one electrode is covered with a very thin layer of hydrogen, that of the other with oxygen. These layers are thus said to be absorbed to the surfaces and are not gaseous.

At the anode, the hydrogen atoms may leave the electron and combine with the negatively charged hydroxyl ions (OH^-) present in the electrolyte to form water molecules. During the process, energy will be liberated and available as power from the cell. How effectively can it happen? Obviously it will depend upon the nature of the electrode surface, temperature and other operating conditions. Grove who was the first to make and demonstrate the working of a fuel cell in 1838 used surfaces made up of finely divided platinum. Bacon, who developed it further, succeeded in 1959 in getting good results with nickel at relatively high temperatures.

The electrons produced at the anode during the above process build up there a negative potential and move to the cathode through an externally connected circuit. Oxygen available at the cathode picks up these extra electrons and reacts with water molecules to form hydroxyl ions (OH^-) liberating energy. The hydroxyl ions combine with hydrogen ions to form water. Again platinum is a good catalyst but Bacon succeeded in using nickel in the form of oxide.

The scheme of reactions can be represented as follows:

At anode, $2H_2 \rightarrow 4H + 4e$
At cathode $0_2 + 2H_20 + 4e \rightarrow 40H$
followed by $4H^+ + 40H^- \rightarrow 4H_20$

The overall reaction can be written as

$$2H_2 + 0_2 + 2H_20 \rightarrow 4H_20$$

In the whole process, the four electrons (or four units of electricity) travel in the outer circuit from one electrode to another giving rise to an electric current. The water finally formed may be removed by evaporation. What is the difference in the processes happening in other cells and here? While the reactants are incorporated in the plates of the other cells, here they are continuously fed as the reaction proceeds. Thus in an ideal fuel cell, with the continuous supply of hydrogen and oxygen at normal temperature and pressure, whole of free energy of formation of water would be converted directly into electrical energy with the result that the cell would operate at 1.23 Volt regardless of the current drawn. This system known as fuel cell would present more efficient utilization of fuel hydrogen than burning it in heat engine where operation is limited by Carnot cycle and the efficiency is only about 40 per cent.

The efficiency of fuel cells is ideally 100 per cent but the figures achieved in practice range from 60 per cent to 80 per cent which is far more as compared to other conventional fuels. Thus because of the high efficiency coupled with light weight, portability, high energy density (*i.e.* more energy per unit weight), high reliability and ability to operate without being attended, the fuel cells have found their use in space vehicles.

The main problem associated with fuel cells is finding effective cheap catalysts for promoting reactions at electrodes while themselves remaining unaffected. Also, the operation of hydrogen-fuelled cells is expensive. Suitable cheap fuels are being therefore searched, *e.g.* natural gas. With gas, however, adequate rate of oxidation is possible at temperatures of the order of 1000° K. In such a case, aqueous alkaline solutions as electrolyte can't be used. Use can be made of solid electrolytes capable of ionic conduction.

8

Biomass Energy

You must have seen persons collecting cattle dung, making its cakes and using them as fuel. Also, you might have used goat's waste as manure for giving energy to plants in your kitchen garden. Are these the only wastes that can be used for energy purposes or any more? What is the potential of such energy sources? Did fossil fuels not originate from the wastes? Can the present wastes be changed to liquids like petrol or diesel? Will you not be astonished if the garbage, a source of pollution in your city, is used to generate power? Finally, what are the prospects of energy, if you grow more plants? Such questions must be coming to your mind while there are talks on bioenergy on Radio and T.V. sets.

In the past, plants and trees and animals have remained buried as wastes for millions of years, what happened to them? The dead organic matter in terms of flora (plants of a region or period collectively) and fauna (animals of a region or period collectively), possibly interacted with earth's internal heat. The process resulted into giving us fossil fuels, *viz.* coal, oil and natural gas.

There are other wastes as well. These come from our houses, industries, farms, forests and other places. Also we grow crops the yield of which can't be used as our food or timber. So, there are a variety of organic waste materials around us. All these wastes and fossil fuels are collectively known as 'Biomass'.

Wastes can be both wet and dry. Wet wastes are in the form of animal or domestic and industrial residues. Dry wastes refer to wood, paper, straw, fruit skin and others. All these wastes can be converted into solid, liquid and gaseous fuels known as biofuels.

Use of biofuels in making a gas known as biogas has generated much interest in our country and China. For this purpose, the raw material, *e.g.* the cattle dung is supplied to insulated air tight containers. Bacteria break it down into simpler chemicals by a process known as anaerobic decomposition. Other bacteria then convert the chemicals into biogas for fuel. The gas consists of mainly methane (about 60 per cent) and is drawn out of the plants. The plants are popularly known as gobar gas plants. While India has about six lakh biogas plants, China has more than 7 million such plants.

The construction of a gobar gas plant is shown in the following figure. It has two main components: digestor and a gas holder. The digestor is a cylindrical well constructed below the

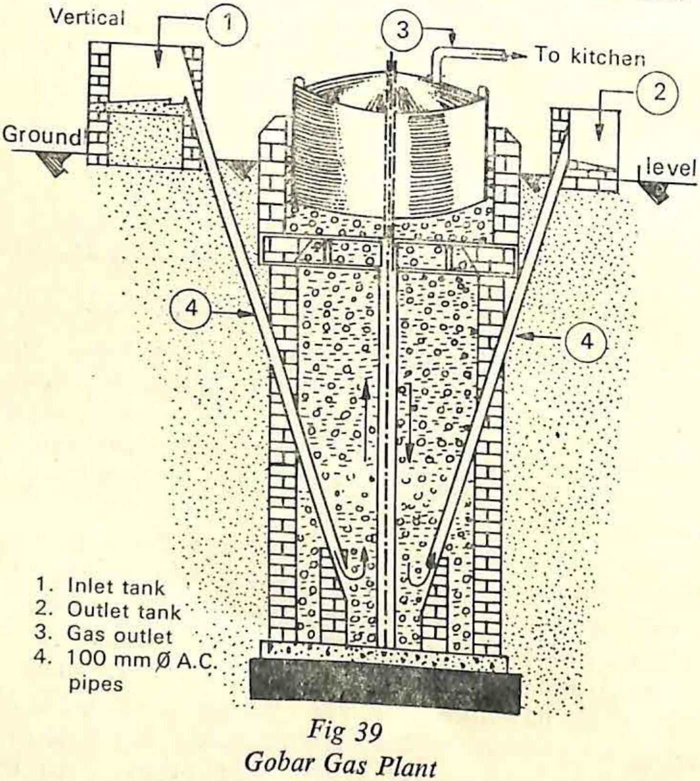


Fig 39
Gobar Gas Plant

ground having a depth varying from 3 to 6 metres and diameter from 1 to 6 metres depending upon the requirement. It is divided into two parts with a wall placed in the middle. Also two slanting tubes made of cement are fitted to the digestor, one on the left serves as the inlet for slurry (cattle dung and urine mixed with water) and the second on the right as the outlet for the refuse. The second component—gas holder—is of drum shape and made up of mild steel. It fits like a cap on the mouth of the well. It dips into the slurry and rests on a ledge built inside the well. A central guide pipe guides the up and down movement of the drum.

Initially, the cattle dung and water is mixed in the ratio 4:5 in a tank and then fed to the digestor through the inlet tube. As the well fills up, an equal amount of used mixture (refuse) is thrown out by the outlet tube whose opening is a bit lower than that of the inlet tube.

When the gas is formed, it bubbles out from the slurry in the digestor and is collected in the gas holder. As the gas collects on the top of slurry in the gas holder, it rises up. The accumulated gas flows out through the gas outlet tube. Normal pressure is 75-150 m.m. of water column, sufficient enough for providing pressure for kitchen stoves, gas lamp etc. within a distance of 30 metres.

Wet wastes from household and industries too can be used to produce methane gas. Wastes may be dumped in deep pits. Wells are then drilled down into the waste. Pipe line is then used to recover the gas produced by the natural decomposition of the materials. The gas thus obtained may provide heat or electricity.

Dumps with heaps of corroding metal wood, cardboard, paper, plastics and others are easily available in any part of the country. In U.S.A., the non-industrial waste annually comprises 48 thousand million cans, 26 thousand million bottles, 65 thousand million metal covers, 6 million junk cars and others. Other countries too have a large amount of wastes or junk and face the problem of disposing it off. For utilizing such garbage a municipal refuse treatment plant has been constructed in Japan. Damp garbage is charged into the plant, evaporated, crushed and transformed into a gaseous mixture. This mixture is then

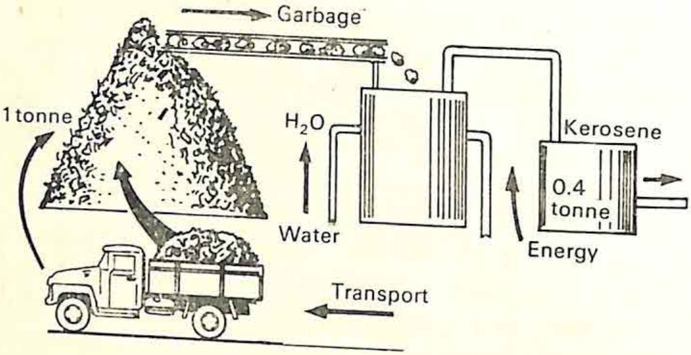


Fig. 40
Plant for processing garbage into fuel

separated and condensed into high and low energy fuels. At the same time, the steam generated in the plant is used for electric power generation. Each tonne of garbage yields about 400 kg. of liquid fuel equivalent to kerosene. In Delhi, a project had been undertaken at Timarpur where a 3.745 MW of power will be generated from 300 tonnes per day of municipal solid waste. Another project for generation of 6 MW of power from bagasse at a co-operative sugar mill in Tamil Nadu was also taken up.

Different techniques are used to get energy depending upon the type of waste. Wastes like wood can be made into chips. Slima (lignin, plastics, uncompressed cellulose etc.), sugarcane bagasse, rice husk, fibres, paper waste, straw, peanut shells, grass and other such agricultural product may be compressed to form pellets or briquetts and then used as fuel in the industries.

In 1930's and during Second World War, attempts were made to convert agricultural waste products into alcohol. Alcohol as such or mixed with gasoline was used in automobiles. Substances like grains, grapes, potatoes, mahua flowers, starchy roots like cassava, palmjuice and others have also been quite common to obtain alcohol. In recent past, Brazil has taken a lead by converting sugarcane directly into alcohol. By 1986, it would be producing some 2-8 billion gallons of alcohol from sugarcane and cassava. Dried wastes, *e.g.* wood chips can also be processed to produce liquid fuels like methanol. This is illustrated in the diagram. Institutes like IIT New Delhi, Madras, and Bombay,

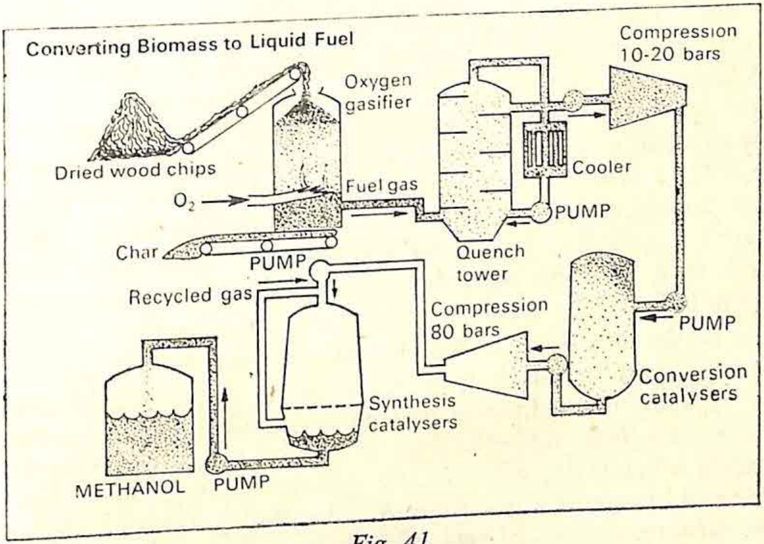


Fig. 41

IIP Dehradun and others have done substantial work in utilizing alternate fuels like methanol, ethanol and biogas to substitute diesel, petrol and kerosene used in vehicular and stationary combustion engines.

Systems to obtain methane from garbage or manure using the process of hydrogasification are being developed. The technique involves reacting carboni-ferrous matter with hydrogen to form a gas consisting mainly of methane. The reaction is accompanied with heat evolution. Thus high moisture municipal refuse can be converted into gas without additional heating.

Another way of obtaining electricity and methane from organic waste is the use of bacterial fuel cells. Electric current is used to ionize water and decompose it into hydrogen and oxygen. Hydrogen, organic waste and methane are directed to a converter known as 'pyrolytic'. As a result crude oil, combustible gas, charcoal and tar are produced. A pyrolysis plant using solid urban refuse is to be set up at Bombay so as to extract liquid fuel from solid refuse through the process of pyrolysis.

Wastes and residues are not the only biofuels. Wood is also a biofuel as it gives you energy when burnt. It is estimated that in India about 80 million hectares of land is lying as barren and waste. The need is therefore to plant the trees like subabul (Leucaena leucocaphala) Acacia species, Neem, Eucalyptus, Albizzias, Sisoo and others so as to get more wood. Wood harvested each year can then be converted by direct combustion or gasification to power and charcoal. About 1000 hectare can provide 3 MW of power besides fuelwood or charcoal which can support energy needs of about 140 families. Calculate how much energy will be at your disposal if the barren land is suitably used. Is it not more than the total installed capacity in the country from all thermal, hydro and nuclear sources?

In the recent past, the emphasis has been laid for growing energy crops specifically for conversion to fuels. Single stem trees and coppiced trees are considered as one form of energy crop. Single stem trees are grown on farm forests. They beside giving wood could contribute thinnings and residues from commercial forests. Coppiced trees result from cutting back the broad leaved trees like poplar, alder, beech, willow and gum so that they regenerate themselves through new shoots. Their growth is much faster than single stem trees in the initial years. They can be repeatedly cut and grown again.

Another technique for obtaining biofuels is growing catch crops during the period a major crop is harvested and another is sowed. Fodder and fast growing weeds are the major choices for catch crops. Work is being done for investigating peat soil conditions and its use as fuel. Experiments are also being carried out on mariculture, *i.e.* growing plants in water both on land and by cultivating algae at sea in special lagoons.

Finally, the analysis will indicate that though the nature provides limited resources for the disposal of wastes yet we can develop many by killing two birds with one stone. We can get rid of environmental pollution because of waste products and tip for the viable alternate energy source. All the more, there will be no hazard such as nuclear one in harnessing bioenergy sources. However for the direct use of wood for combustion, fuel efficient stoves are to be prepared. At the same time it will be more efficient to convert wood to charcoal which has the additional advantage of burning smokeless.

9

Solar Energy

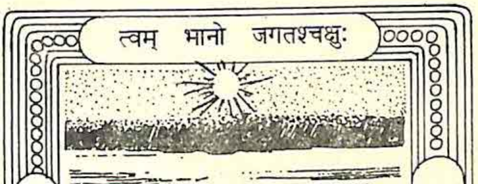


Fig. 42

Tvam Bhano jagataschhakshuh,
Tvam atma sarvadehinam,
Tvam yonih sarvabhootanam
Tvamacharah kriyavatam.

—Yudhishthira in *Mahābhāratam*

That is,

> You, O Sun, are the eye of the world,
> You are the soul of all embodied beings,
> You are the source of all creatures,
> You are the discipline of all engaged in work.

You know how to light your torch bulb with a dry cell. Also you have read about the energy available from the interior of the earth, *i.e.* geothermal energy. The villain of energy—nuclear energy—too has proved to be a powerful source of energy these days. But for these sources, there are many other conventional and non-conventional resources of which the source of energy is directly or indirectly the sun. In fact since the birth of this planet earth, the sun has supplied all the energy it needed to grow and evolve. This has of course been in different forms, *e.g.* light and heat, wind and rain in an endless cycle, leading to wind power and hydro-power respectively, firewood, the fossil fuels, *i.e.* coal, oil and natural gas and the bio-energy. With the ever increasing need and the fast vanishing fossil fuels scientists are now trying to harness the direct as well as immediate use of energy obtained from the sun termed as solar energy.

In India too a number of persons use solar cookers, solar calculators and solar heaters. In Bitra, in the Lakshadweep islands, people get drinking water after sea water is desalinated by 750 square metre solar still. In a remote village in Bihar, tribals draw water using solar pumps. A railway station is run on solar cells near Bangalore. Besides, many hotels and industries use solar energy to heat water. The energy to all these systems comes from the sun—what a tremendous source at no cost to us! What does the sun light have?

Hold a prism in your hand. With one refracting surface projected towards sunlight, look through the other. What do you observe? Sunlight called as white light breaks up into a number of colours. This combination of different colours is known as the spectrum of white light. Issac Newton was the first to conclude in 1668 that the white light is composed of seven colours. Scientists characterize the different colours of white light by different 'wavelengths' because they are seen to possess different energies. We see colours when light of different energies fall

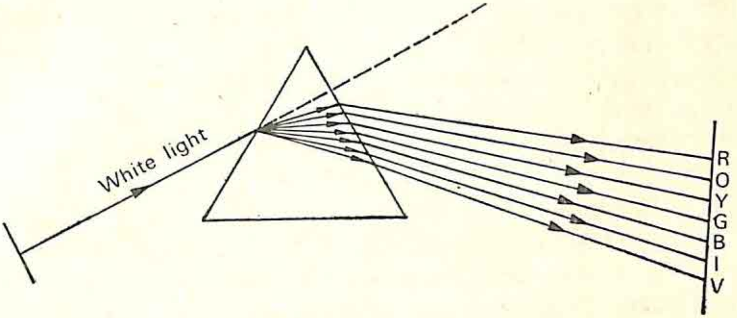


Fig. 43

Prism splits white light into seven colours

upon the sensitive surface of the eye. Thus white light is considered as a combination of several colours or energies. At times we refer to them as having radiation of different wavelengths. In the present case, prism has separated them.

Investigations with sophisticated detectors, more sensitive than our eyes, reveal that besides the above radiations in the white light there are other two radiations, *viz.* infra-red and ultra-violet radiations. Ultra-violet radiation in sunlight causes sunburn. It also helps in making vitamin D in our skin. When infra-red radiation is absorbed by a body, it gets warmer. This is why we feel warmer in sunlight. Ultra-violet radiations can be produced by special lamps. Infra-red radiations are produced to some extent by objects at all temperatures. Both types of radiations can be used for taking photographs under particular conditions. Ultra-violet radiation may be used for health and beauty reasons. Also, they are used to identify minerals because some rocks glow (fluorsce) while absorbing them.

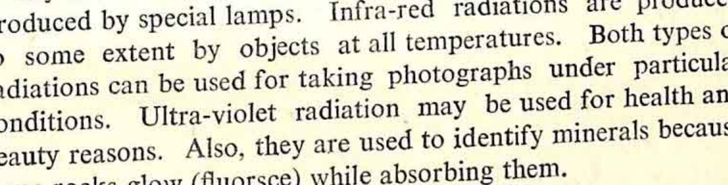


Fig. 44

Further examination of the energy released by the sun also indicates the existence of X-rays and other radiation detected by radio-telescope. These radiations like ultra-violet and infra-red are not visible to the naked eye. The following diagram shows all the above radiations and they form a spectrum known as 'electromagnetic spectrum' as obtained for the solar energy.

Different parts of the spectrum possess different energy but interestingly each radiation moves with the same speed, the speed of light, irrespective of its position in the spectrum. Also, the light energy and heat energy in the radiation travel with the same speed. It is obvious, as we know that a cloud across the sun reduces both of them simultaneously.

Ultra-violet radiation has more energy than the visible part which in turn has more energy than the radiations detected by radio-telescopes. When the energy coming from the sun, *i.e.* solar energy strikes the earth's atmosphere some of it is reflected by the dust particles and clouds, some of it is absorbed by Co_2, water vapour, ozone layer etc. and the remaining reaches the earth's surface. Much of the ultra-violet radiation is absorbed by the ozone layer making life possible on earth's surface. Some infra-red radiation is absorbed by clouds, carbon-dioxide and water vapour. Amount of radiation reaching the earth thus may vary with the presence of clouds, humidity, the latitude—the position of the place north or south of equator—the time of year, the time of day and other factors. However, on a clear day, the

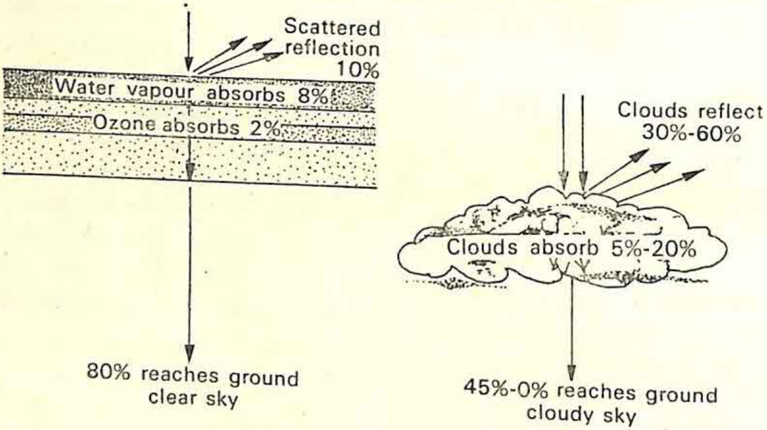


Fig. 45

energy reaching the earth comprises about 10 per cent ultraviolet, 45 per cent visible and 45 per cent infra-red radiations.

What happens to these radiations on reaching the earth? Let us see it with a few examples. We know that it is difficult to walk barefoot on a road in summer. We get warm water from the overhead tank. Such examples show that the radiations are absorbed. What happens to a paper when concentrated light from a convex lens is made to fall on a paper? It burns. This indicates that the radiations are transmitted through certain surfaces. Similarly, light concentrated with the help of mirrors, if allowed to fall on a can containing water, makes water to get heated soon. This shows that the radiations are reflected too. Also, if we stand in front of a wall in the evening in summer, we feel warmer than if we are in the open. It shows that the absorbed radiations are re-radiated as well. Thus several such examples lead us to conclude that the solar energy may be (a) reflected (b) transmitted (c) absorbed and (d) re-radiated depending upon the kind of surface. So any device making use of solar energy will work upon any single or combined effects given above.

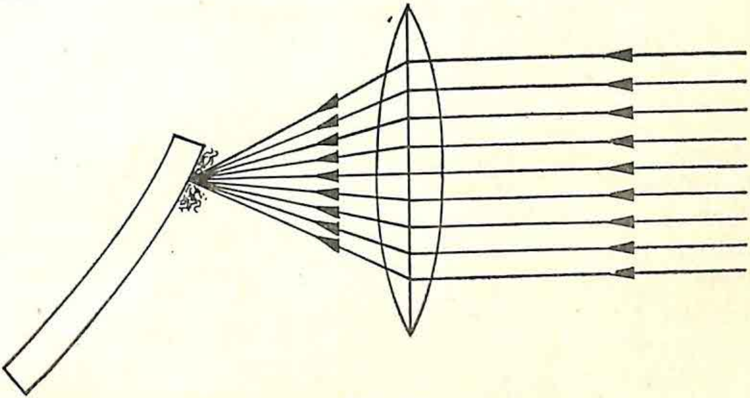


Fig. 46

Sun's rays concentrated on paper using a convex lens

It is estimated that out of all the energy falling on earth, a third is reflected back into the space, a fifth drives the hydrologic cycle and about 47 per cent is still available for conversion. The magnitude of this source of energy can be understood by noting that on a clear day the solar energy falling on an area equal to the size of a tennis court is roughly equal to the energy obtained by 135 litres of petrol or 180 kilograms of coal. What a tremendous source with no cost to us has been provided by nature. In India, the conditions are quite favourable as far as the amount of solar energy falling in any city is concerned. Look at the following data:

Solar radiation in some representative locations in India
(in megajoules/square metre/day)
(I megajoule=10^6 joule & I calorie=4.18 joule)

Location	*Maximum*	*Minimum*	*Average*
Madras	32.0	25.3	30.1
Bangalore	31.2	23.5	27.9
Bombay	33.2	22.6	29.3
Calcutta	34.1	20.9	28.5
Delhi	34 6	17.6	27.4
Srinagar	30.8	10.0	26.4

With such an optimistic amount of energy available with us and realizing its variable nature as well with respect to time, day,

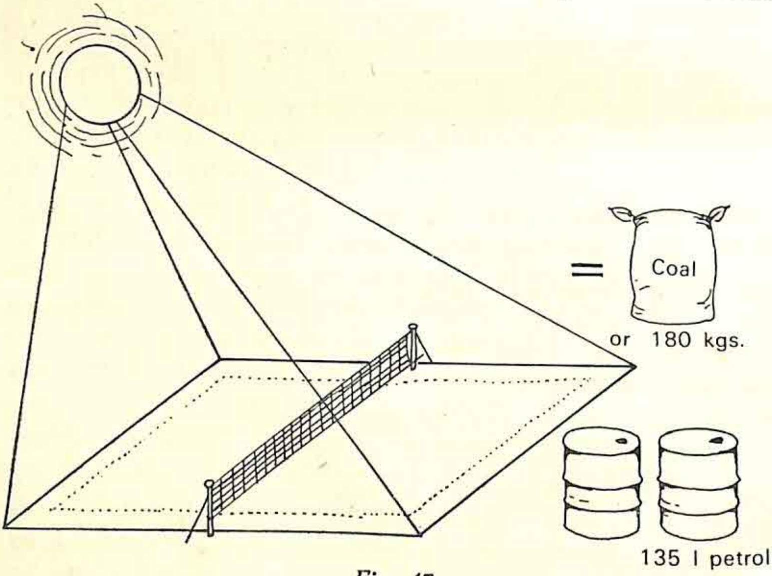
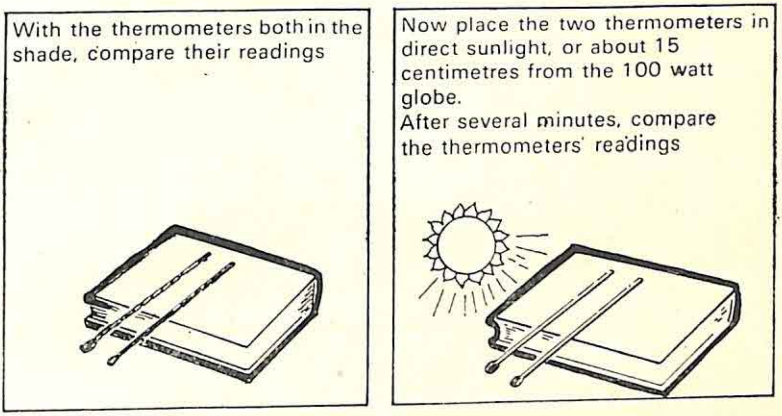


Fig. 47

season, place and other factors, various institutes and several agencies in private and public sector are trying through various means to store, convert in other forms like electricity and make the energy more concentrated. Let us see, how?



With the thermometers both in the shade, compare their readings

Now place the two thermometers in direct sunlight, or about 15 centimetres from the 100 watt globe.
After several minutes, compare the thermometers' readings

Fig. 48

Which surfaces absorb the maximum radiations? Take two thermometers reading upto 110°C, one with a silvered bulb and the other blackened with a black paint or colloidal graphite. Place the thermometers in direct sunlight and record the temperature after several minutes. Why does the thermometer with a blackened bulb read more? We can try with other type of colou-

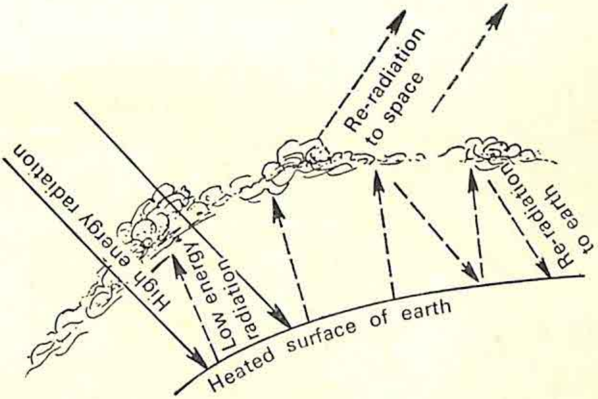


Fig. 49 (a)

red surfaces. It is seen that the surface which is blackened absorbs maximum radiations.

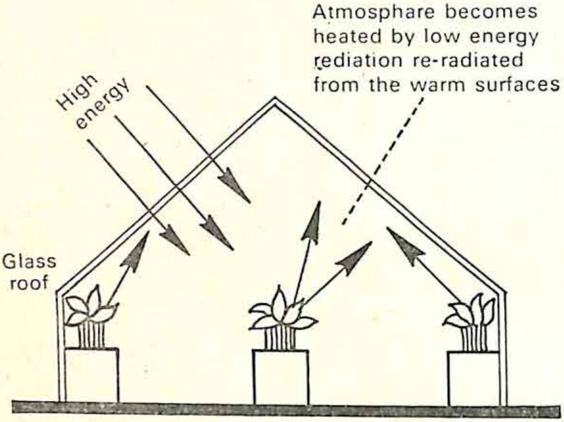

Atmosphare becomes heated by low energy rediation re-radiated from the warm surfaces
High energy
Glass roof

Fig. 49 (b)

The second important aspect concerns with the flow of radiation between the earth and the atmosphere. It is known as Greenhouse effect. As quoted above, some high energy radiations (ultraviolet radiation) are able to penetrate through the atmosphere without being completely absorbed. Such radiations heat the surface of earth which in turn re-radiates low energy infra-red radiation. These low energy radiations in part are absorbed by the lower atmosphere. Again, the lower atmosphere re-radiates some energy towards the earth's surface and some into space. A similar effect takes place in a greenhouse with a glass roof. Thus a glass cover may suitably be utilized to control the escape of radiation to some extent from any solar cooker or heater.

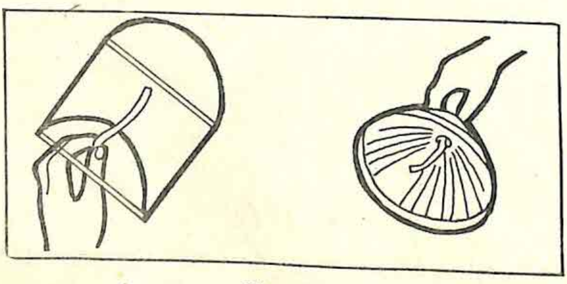


Fig. 50

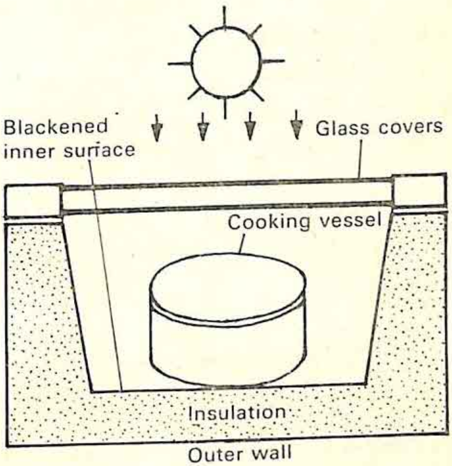
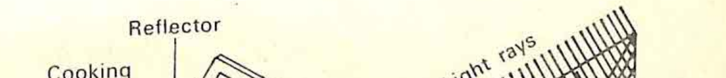


Fig. 51 (a)
Some hot box solar cookers

Thirdly, as the solar energy is spread up over a larger area, the problem is to concentrate it over a smaller area or a point. To have an idea, take a piece of cardboard. Stick over it a sheet of aluminium foil. Bend it to give a shape as shown in the figure. You may use adhesive tape to keep its shape. Point your reflector towards the sun. Move a small paper strip in various positions at the centre of the reflector. When a bright spot on the paper is formed, hold it steady for sometime. What happens to the paper? Why does the paper burn? You could do



Box cooker with single reflector Solar ovens use multiple reflectors

Fig. 51 (b)

the same with a convex lens. Which method is preferable to concentrate energy and why?

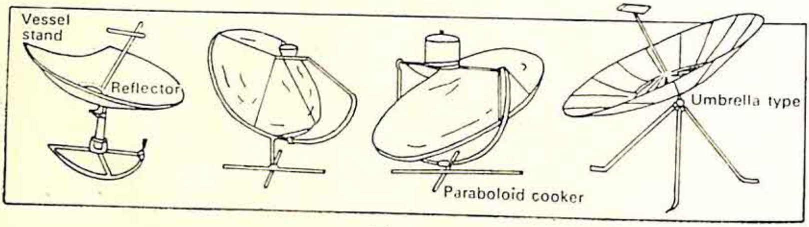


Fig. 52
Different shapes of reflectors may be used for focussing solar radiations

There are several types of reflectors particularly used in solar cookers. The simplest is a single reflector provided in hot box type of solar cookers. The reflector is a sheet of polished or electroplated looking glass or aluminised plastic hinged to one side of the box which reflects solar radiation into the cooker and

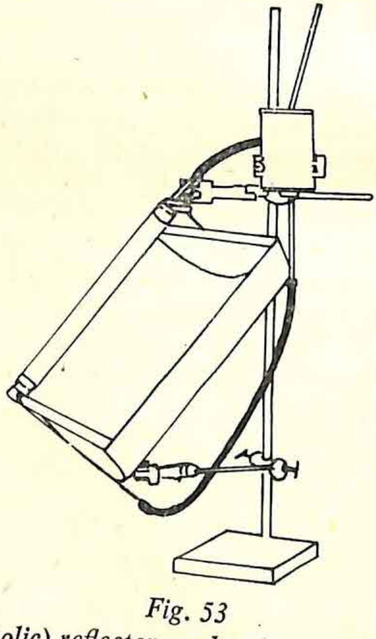


Fig. 53
A curved (parabolic) reflector used to heat a container of water

enhances its energy input. In a solar oven, several reflectors (fixed or collapsible) are provided on all the sides of a box.

Curved mirrors or parabolic reflectors have also been used in solar cookers. You can make one using a car headlight reflector. The same type may also be used to heat water in a container by concentrating radiation on it. Try, if you can heat water in a test tube by using this type of reflector.

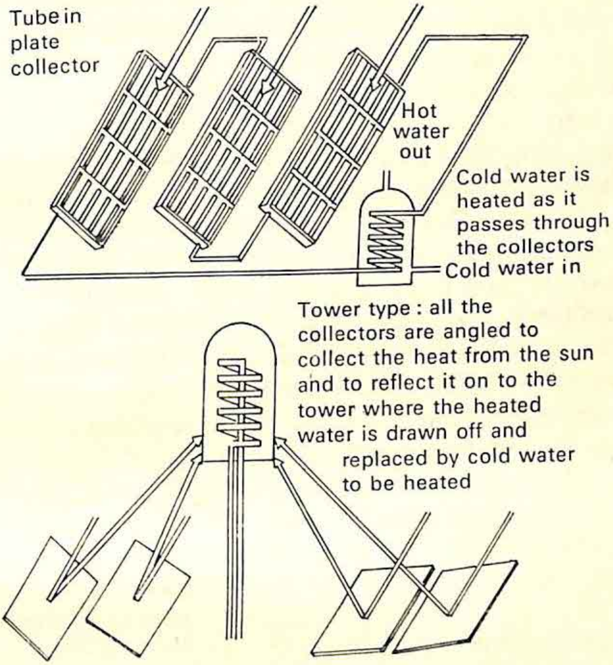

Tube in plate collector
Hot water out
Cold water is heated as it passes through the collectors
Cold water in
Tower type : all the collectors are angled to collect the heat from the sun and to reflect it on to the tower where the heated water is drawn off and replaced by cold water to be heated

Fig. 54

Collectors are used for water heating systems

Curved mirrors in combination just like an umbrella type may be used to concentrate radiations still more. In Cairo, a power plant was constructed between 1906 and 1914 using five curved mirrors. Each curved mirror was 4 meters across and 60 meters long with a total area of 1200 square meters. The absorbed energy was used to produce steam and in turn to drive an engine and a water pumping unit with a power of about 15 kilowatts. Can you visualize the problem if such huge units are used for power generation? How difficult will it be to adjust the mirrors to follow the sun?

For heating water, it is not economic to concentrate radiation. The mechanism required to follow the sun is quite costly and complex as well. It is for this reason that solar water heaters are provided mostly with flat plate collectors. A wide variety of flat plat collectors is available. However, a tube-in-plate collector is generally used. The system has a plastic or metallic plate with single or double cover and is selectively coated or painted black. It is fitted with several tubes. The plate as well as tubes may be made up of any of the material like copper, aluminium, steel, stainless steel, galvanised iron etc.

What direction should the collectors face for the greatest amount of sun? Obviously towards the equator, *i.e.* true south in the northern hemisphere, *e.g.* in India and true north in the southern hemisphere, *e.g.* in Australia. It has also been estimated that for maximum radiation to be collected, the collector tilt from the horizontal should be equal to the latitude (L) of the place plus 15 degrees, *i.e.* (L+15)° in winter season. In summer and year round, the collector tilts should be (L-15)° and 0.9° respectively. On a clear day, a square meter of collector area can heat 50-70 litres of water upto 55°-60°C.

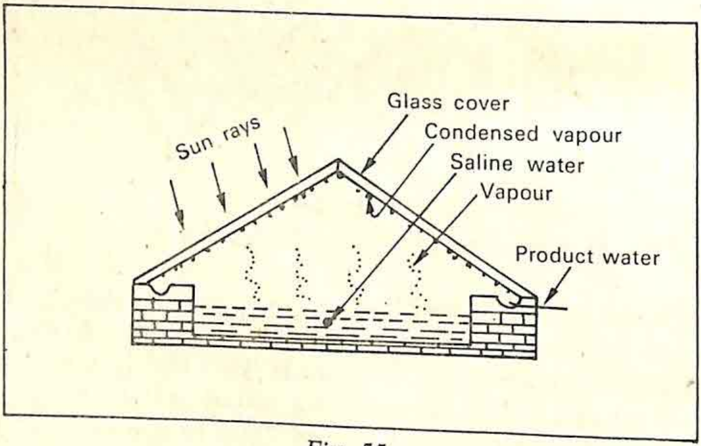


Fig. 55
Principle of solar still

Collectors have been put to use in many systems based on solar energy and are referred to as collector panels. These have found their use in the heating or cooling of the houses or offices, refrigeration as well, solar ponds, solar driers, water pumps for irrigation, solar stills to convert saline well water into drinking water and others. As an example we will discuss the case of solar still and leave for readers to understand the working of others with the help of diagrams.

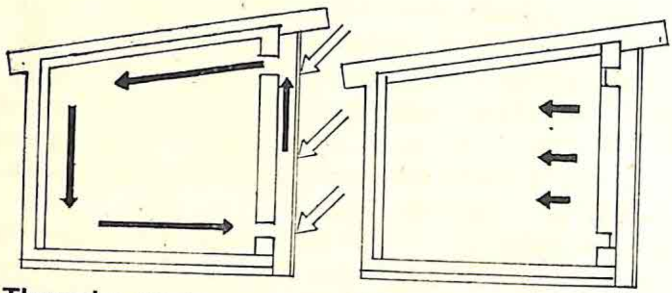
In our country, many wells are seen to have saline water. How can we provide drinking water in such areas? Can't we use sea water for drinking after removing its salinity? Yes. This is made possible by solar energy. Systems known as 'solar still' do it. A 750 square metre solar still desalinates sea water to provide drinking water in Bitra, in the Lakshadweep islands. In Narayan Sarovar in the Coastal Kutch district in Gujrat, a solar still has been set up to desalinate water from wells and provide salt-free water to nearby villages. What is this solar still and how does it work?

Solar still consists of an enclosure with black bottom (to increase the absorption of solar radiation) and a roof made up of glass or covered with transparent plastic. It works on the natural water cycle of evaporation and condensation. Water in the enclosure is heated by sunrays and evaporates. The glass or the plastic cover helps in retaining heat inside the still by 'greenhouse effect'. Also as the underside of glass acts as a cool surface, water vapour condenses on it. It is then collected as drinking water through flow channels fixed at lower edges of the cover which is sloped to facilitate the flow.

Have a look at Figures 56(a), (b), (c) and (d). How do the following work?

(a) Heating the houses
(b) Solar assisted refrigeration system
(c) Solar drier
(d) Solar water pump

The use of collectors has also been suggested for driving electric generators. The system could consist of erecting panels covered with selective coatings (collector panels) into large areas of desert where amount of solar radiation is in plenty. The absorbed heat may be used to produce steam which in turn can run the electric generator.



Thrombe system
Named after Dr. Felix Thrombe, a passive system featuring thick concrete stone or masonary walls. The sun heats the air between the Thrombe wall and outer glass.

The hot air rises and enters the room through the top vent. The cooler air is drawn through the bottom vent and is re-heated. At night, shutters are closed over the vents. Heat radiates from the wall which has absorbed the sun's heat.

Fig. 56 (a)
Uses of solar collector

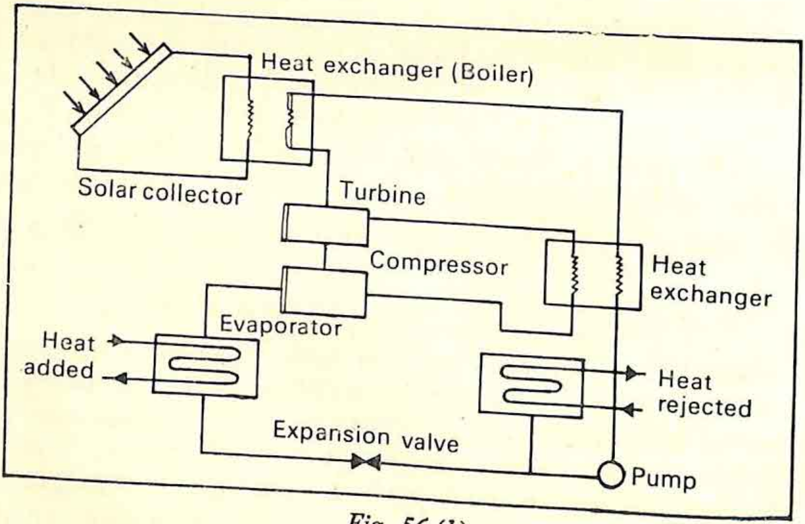


Fig. 56 (b)

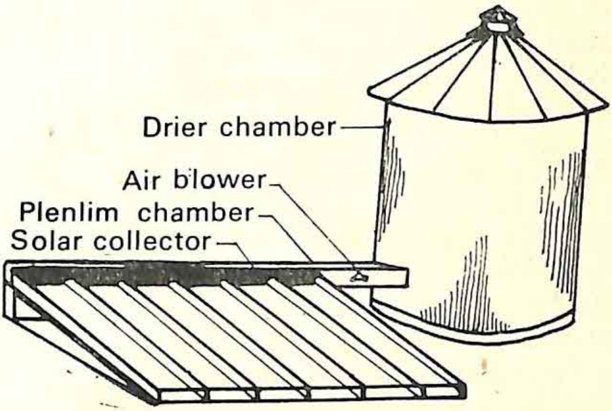


Fig. 56 (c)

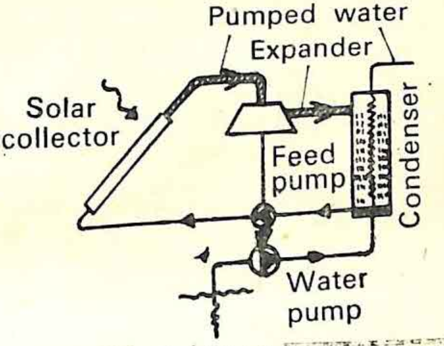


Fig. 56 (d)

Other methods such as OTEC for electric power generation, discard the use of collector panels and instead make use of thermal gradients set up in ocean water for evaporating a liquid having low boiling point. For details see chapter 3 on 'Energy from Oceans'.

However, the best alternative which can convert the radiant energy of sunlight directly into electricity and looks to be quite promising is the development of solar cells. The working of a solar cell depends upon the phenomena of photo-electricity, *i.e.* the liberation of electrons by light incident on a body. Though the principle was known for a long time, but its application to semi-conductors has proved to be of great use. The basic principle is quite simple. If one n type and the other p type

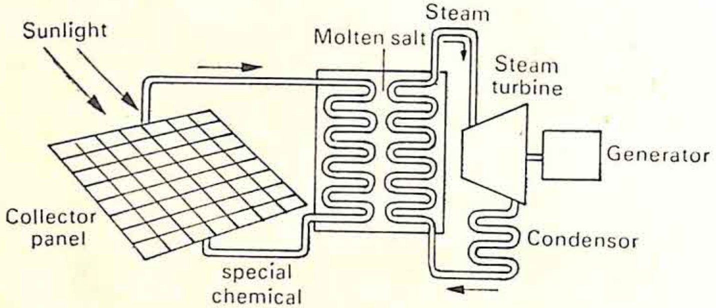


Fig. 57
Use of solar energy to run an electric generator

semi-conductor are placed in contact, a potential difference is developed at the inter-face because of the diffusion of electrons. Now if p-type semi-conductor is exposed to light, its electrons

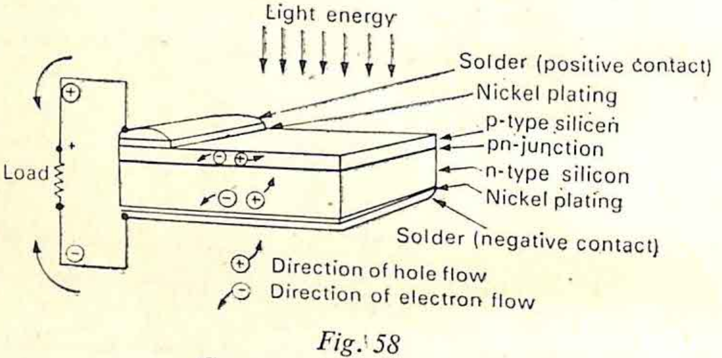


Fig. 58
Cross section of a solar cell

absorb photons of light and pass into the n-type semi-conductor. It thus generates an electric current in the circuit. Devices based on this principle are known as photovoltaic (PV) devices and make use of silicon made solar cells. The overall efficiency of such cells is around 11 per cent. These cells are by far quite costly and require cheap technology. Attempts have therefore been made to replace them by multi-grain silicon wafers, amorphous silicon cells and silicon ribbons. Multigrain silicon cells have 1 or 2 per cent low efficiency and are not cheaper than silicon cells. Amorphous silicon cells are estimated to be cheaper to produce but they have an overall efficiency of about 4 to 6 per cent only.

Therefore, these cells are not much suitable for outdoor power generation. However, they are used in pocket calculators, electronic games and watches and for small nickel-cadmium battery charging. For silicon ribbon cells also, cheap technology is yet to be developed.

Nevertheless, it has been proposed that solar powered photovoltaic devices be arranged in space on man-made earth-circling satellites. They will then store the energy 24 hours a day. The energy thus trapped may be transmitted to the earth in a sufficiently narrow microwave beam (of about 10 cm wavelength) using a transmitting antenna. On the earth, the energy beam

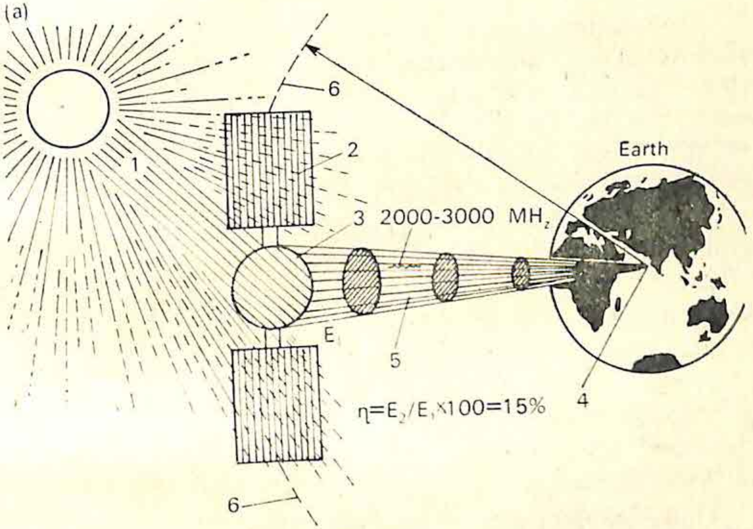


Fig. 59

Solar power plant carried by man made satellite

1. Solar energy radiations
2. Transmitting antenna
5. Microwave beam.

2. Solar cell panels on satellite
4. Receiving antenna
6. Synchronous orbit of power generating satellite (at a distance of 30-40 thousand Km. from earth's surface).

may be received by a receiving antenna. Finally, it can then be converted into commercial frequency electric power.

Besides the above processes known as photophysical processes, chemical means are also being tried out to trap solar energy and produce either electricity or valuable fuels and chemicals. To obtain electricity, photoelectrolytic cells have been prepared. The basic principle in such cells is that any cyclic system in which the endergonic photochemical reaction

$$A \xrightarrow{h\nu} B$$

takes place is followed at a later time by the reverse exergonic processes, *i.e.*

$$B \rightarrow A + \text{useful work.}$$

Photoelectrolytic cells are of two types, *viz.* liquid junction photovoltaic type and photogalvanic type. While in the former electrodes made up of semi-conductors are used to absorb solar energy, in the latter it is the solution which absorbs the light energy. Under suitable conditions, the reactions are reversed and chemical energy is released as electrical energy.

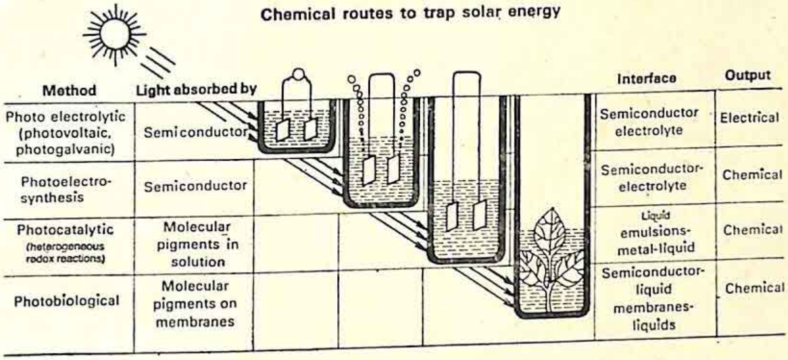
To produce fuels or chemicals using sunlight the photoelectrosynthetic, photocatalytic and photobiological cells have been prepared. Photoelectrosynthetic cells primarily produce fuels like hydrogen by splitting water. Hydrogen is considered as an attractive fuel for the future, *e.g.* in fuel cells discussed earlier.

Photocatalytic cells produce chemicals which are expected to be cheaper. They can be used to synthesise a variety of chemicals, ethane, formic acid, amino-acids among them and for fixing nitrogen into ammonia.

Photobiological systems make use of the process of photosynthesis in plants. Energy is stored by plants using this process. Similarly we can convert plant carbohydrates into a more useful liquid fuel, alcohol, by fermentation.

All the above methods are interrelated. The general approach is to catalyse chemical, electrochemical and biological reactions using sunlight. The main drawback associated with these processes so far is the low efficiency of solar to chemical conversion. Only photogalvanic cells have reached a commercial stage. Still they are not competitive with other electricity generating systems.

It is thus obvious that with improved techniques the solar



Chemical routes to trap solar energy

Method	Light absorbed by	Interface	Output
Photo electrolytic (photovoltaic, photogalvanic)	Semiconductor	Semiconductor electrolyte	Electrical
Photoelectro-synthesis	Semiconductor	Semiconductor-electrolyte	Chemical
Photocatalytic (heterogeneous redox reactions)	Molecular pigments in solution	Liquid emulsions-metal-liquid	Chemical
Photobiological	Molecular pigments on membranes	Semiconductor-liquid membranes-liquids	Chemical

Fig. 60

energy is going to be our ultimate bet. Besides, its use has several advantages over other energy sources. Sun's energy is inexhaustible. It is clean as the transformation as well as the direct use of solar energy is free from any pollution unlike the promising nuclear energy leading to radioactive hazards. Unlike fossil fuels and nuclear fuels, transformation of solar energy does not produce any unwarranted by-products. No nation can cut off the supply of another nation. Also, the maintenance of the installations is not expensive. However, the problem with solar energy is that the sun does not always shine. The energy is too diffuse and intermittent. Efficient mechanism and systems for its collection and concentrating it are crucial. Initial installations are expensive. The storage mechanisms are to be more efficient and cheap as well. Suitable materials with desirable radiative properties are to be paid more attention.

Perhaps, the maximum use of solar energy will be for low temperature applications in future unless a major breakthrough takes place in harnessing this energy. Of course, satellite mounted solar power plants are the future hope for using this energy commercially.

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Of allied interest

PLASMA: The Fourth State of Matter
—H.C. Jain

To meet the global energy crisis, a search has begun for alterna sources of energy of which plasma is considered the most promising. The study of plasma among students remains neglected. They are unable to link it with the basic concept of matter and energy. This book introduces and explains plasma as the fourth state of matter in a simple way with the help of diagrams. Written in popular style, it should help students understand plasma and its potential as a future source of energy.

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